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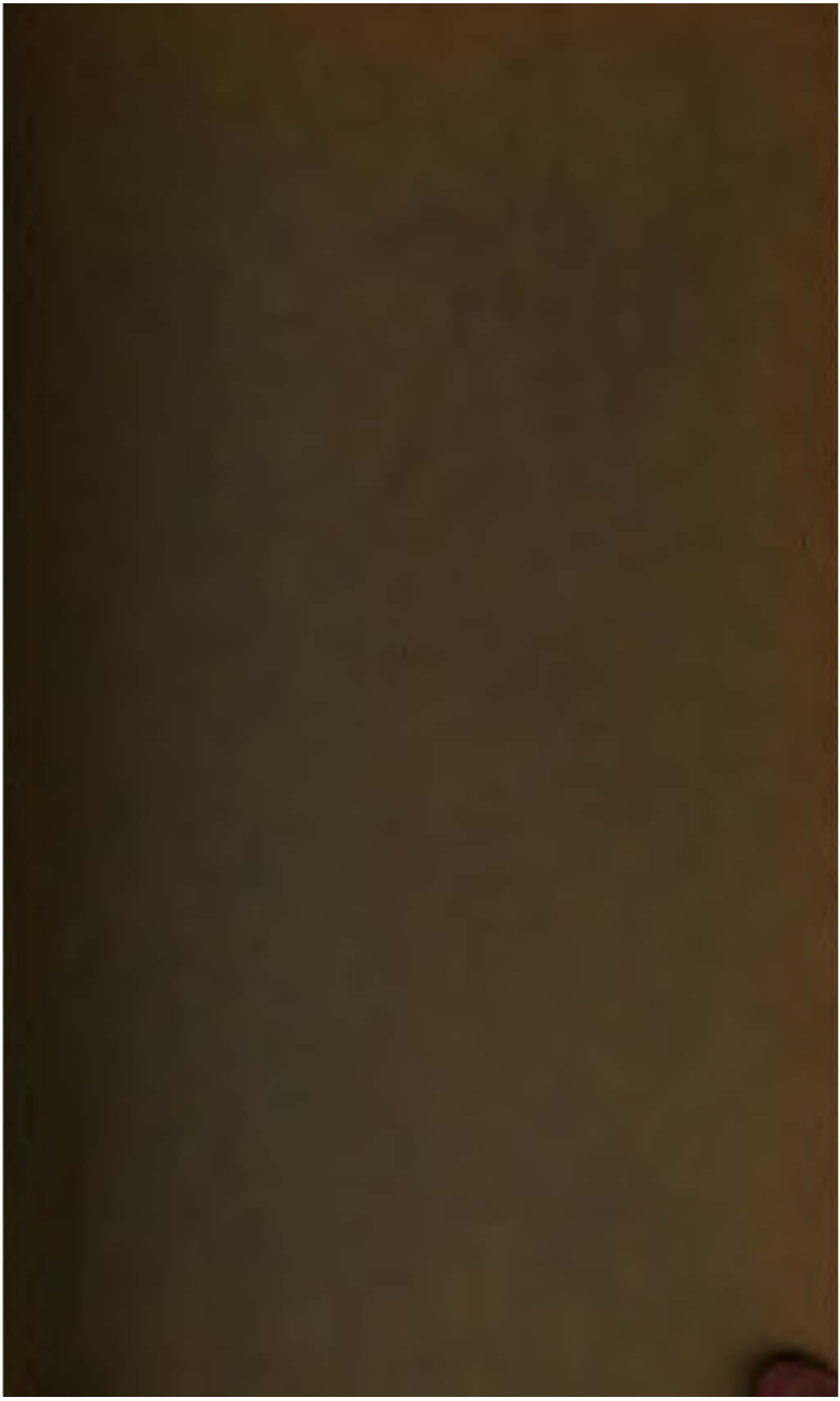

President
Chas. Kendall Adams
with compliments
the Author
October 12th
1885.

A TEXT-BOOK

OF THE

MATERIALS OF CONSTRUCTION,

FOR USE IN TECHNICAL
AND ENGINEERING SCHOOLS.

ABRIDGED FROM "MATERIALS OF ENGINEERING."

BY

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PREFACE.

THE volume which is here presented to the profession is an abridgment of the larger work of the author, "Materials of Engineering." It is prepared for the purpose of supplying to students and instructors a text-book, for use in private reading, and in those colleges and technical schools in which the time which would be demanded for the larger work cannot be given to the subject. It is only in special schools of engineering, and rarely, even in them, that more than a small part of the matter contained in the three volumes of the larger treatise can be taken in the class-room. The Author has, in his own course, used a part of the first and second volumes, and has summarized in lectures the principal facts contained in the third; but even a special school of mechanical engineering cannot afford time for more than this, or, indeed, perhaps, as much.

An abridgment has, therefore, been prepared, in which the essential parts only of the earlier treatise have been retained. The volume thus constructed is of manageable size, is of such comparatively low cost that it can probably be brought into use in any technical school; and yet it contains enough of the matter collected in the extended work to furnish a basis for the course in construction and machine-design taught in the most elaborate course yet adopted in any such schools. The origin, nature, method of preparation, and the useful properties of all the common, and so-called useful, metals, and their strength, elasticity, and other qualities essential to their introduction into the various constructions which the engineer is called upon to build or to inspect, are

treated of at considerable length, and the influence of the more common conditions affecting them is studied.

The chapters on the reduction of the ores of the metals are substantially as complete as in the unabridged work; those treating of the properties and uses of those metals are but slightly condensed; and the portion of the treatise relating to the alloys retains the more essential facts. In the condensation of the matter found in the original, the effort has been made to select for excision, mainly, the parts which give at great length the details of the less important processes, and the less essential data obtained by experiment; while the general, and the average, results are retained, as being essential information for the designing engineer.

In the text, "Materials of Engineering," refers to the larger work.

DIRECTOR'S ROOMS, SIBLEY COLLEGE, CORNELL UNIVERSITY,
ITHACA, N. Y., *September*, 1885.

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MATERIALS OF CONSTRUCTION.

THE USEFUL METALS.

CHAPTER I.

HISTORY AND CHARACTERISTICS OF THE METALS AND THEIR ALLOYS.

The knowledge of metals possessed by the early races of mankind was of the most inexact and unsatisfactory character. They were probably led to seek a method of utilizing them, first, by the demands of their fighting classes. Their structures, their implements of agriculture and war, and their domestic utensils were, in the earliest stages of their race-history, of wood, bone, and stone. All races are found to have advanced to their present condition of civilization from a primitive state of barbarism, in which they were entirely ignorant of the use of metals, and knew nothing of even the simplest processes of reduction.

The weapons of mankind, in prehistoric times, were at first made of hard wood, of bone, or of stone, fashioned with long and patient labor into rude and inefficient forms. As the race advanced in knowledge and intelligence, they acquired, by some fortunate circumstance, a knowledge of the methods of reducing from the ores the more easily deoxidized metals, and, still later, those which cling with tenacity to oxygen, and require considerable knowledge and skill, and special apparatus for their reduction to the metallic state; and at a still very early period, they applied the more common and more generally useful metals in their rude manufactures.

It has thus happened, that mankind has passed through what are designated by the geologists as the ages of stone, of bronze, and of iron, and may be considered as having just entered upon an age of steel.

The ancients, at the commencement, and immediately before the Christian era, were familiar with but seven metals.

The earliest of historical records indicate that, long previous to their date, some metals were worked, although with rude apparatus, and in an exceedingly unintelligent manner. Tubal Cain was an artificer in brass and in iron; and several sacred writers refer to the use of these metals and of gold and silver, in very early times. Profane writers also present similar testimony; and the discovery of implements of metal among the ruins of the ancient cities of Asia and Africa, and in the copper mines and other localities of North America, indicate that some knowledge of metallurgy was acquired many centuries before our era.

The Hebrews were familiar with gold, silver, brass (bronze ?), iron, tin, and lead, and possibly copper and other metals.

Bronze and brass were not always distinguished by ancient writers, but both alloys were known at a very early date. Phillips gives analyses * of a number of samples of the latter dating from B.C. 20 to B.C. 165, and bronze was certainly made much earlier. Zinc was known in the metallic state at some early date, while tin was known in the earliest historic times.

The Chinese, at a time far back of even their oldest historical records and traditions, seem to have been workers in iron and in bronze.

Evidence has been found, in Hindostan, that the inhabitants of the Indian peninsula, at an era of their history of which we have lost every trace, were able not only to reduce these metals from their ores by rude metallurgical processes, but that they actually constructed in metal, works which are looked upon as remarkable for their magnitude.

The Chaldeans, four thousand years ago, the Persians, the

* Metallurgy, 1874, p. 6.

Egyptians, and the Aztec inhabitants of America, if not an earlier race, had some knowledge of the reduction and of the manufacture of metals.

The "Bronze Age," in Europe, is supposed to have originated in the south of England, and to have gradually spread over Europe, a knowledge of the methods of working copper and bronze finally becoming very general. The bronze age of Central America antedated that of Northern America, where the contemporaneous age was that of copper.

It is probable that copper may have been the first metal worked by these early metallurgists, and that tin was next discovered and used to harden the copper, as is done at the present time. In the manufacture of bronze, the ancients became very skilful, probably long before the discovery and use of iron. The bronze implements discovered on both continents have sometimes nearly the hardness and sharpness of our steel tools.

It is only within a comparatively recent period, however, that metallurgy has become well understood. To insure its rapid and uninterrupted progress, it was necessary that the science of chemistry should be first placed upon a solid basis, and this was only done when, about a century ago, Lavoisier introduced the use of the balance, and by his example led his brother chemists to employ exact methods of research.

The valuable qualities of the metals used in construction are very greatly influenced by the presence of impurities, and by their union with exceedingly minute quantities of the other elements, both metallic and non-metallic.

In the processes by which the metals are reduced from their ores and prepared for the market, there is always greater or less liability of producing variations of quality and differences of grade, in consequence of the impossibility of always avoiding contamination by contact with injurious elements during these operations, even where the ore was originally pure.

In the time of Lavoisier, but seventeen substances were

classed as metals, and of these the characteristics upon which the classification was based were principally physical, and the place of newly discovered elements was long uncertain. Potassium and sodium were at first (1807) classed as non-metals.

The distinction between metals and metalloids remains somewhat indefinite, and the type metal is considered, necessarily, ideal. The metals are usually solid, mercury being an exception; they are usually liquefiable by heat, but arsenic is volatile without fusing; they are generally opaque, but gold is, in very thin leaves, translucent; they are nearly all malleable and ductile, but in very variable degrees. The metals are good conductors; the metalloids are not. The metals are electro-positive, as a rule; the metalloids electro-negative.

Metallurgy is the art of separating the metals from the chemical combinations in which they are met in nature, freeing them from impurities with which they may be mechanically mingled, and reducing them to the state in which they are found in our markets, and in which they are adapted for application in construction.

The chemical combinations from which the useful metals are obtained, are usually either [illegible] number of samples of the [illegible] oxides. The common ores of iron are [illegible] and bronze was certainly anhydrous, and copper is gen[illegible] the metallic state. [illegible] perior mining region of the United States, reduced [illegible] state of sulphide.

Lead is usually found combined with sulphur, forming the sulphide known as galena.

Zinc is found and mined as an oxide, as a sulphide, and also as carbonate and silicate.

The sulphide of iron is rarely or never mined as an ore of iron, although abundantly distributed in the form of pyrites.

The following table* illustrates the general character of the chief chemical processes employed for the purpose of reducing metals of ordinary occurrence from their ores.

* *Metals and Applications.* G. A. Wright, London, 1878.

REDUCTION PROCESSES IN USE.

I.—*NATIVE METALS.*

By mechanical means..... *e.g.* gold washing.
By simple fusion (liquefaction).... *e.g.* bismuth.
By solution in mercury..... *e.g.* gold-quartz.
By solution in aqueous chemicals.. *e.g.* gold-quartz.

II.—*SIMPLE ORES;* i. e., *containing only one metal.*

A.—Oxides.

Analytic.....	By simple heating.....	*e.g.*	mercury, silver.
Single decomposition...	By heating in hydrogen.....	*e.g.*	nickel, iron.
	By heating in carbon oxide.....	*e.g.*	iron (blast furnace).
	By heating with carbon (coal, coke, etc.).....	*e.g.*	tin, arsenic, zinc, iron, antimony.

B.—Chlorides, Fluorides, etc.

Analytic.....	By heating alone.....	*e.g.*	platinum, gold.
Single decomposition...	By heating in hydrogen.....	*e.g.*	silver.
	By action of cheaper metal, etc.		
	By (*a*) wet processes.....	*e.g.*	copper, gold.
	By (*b*) dry processes.....	*e.g.*	magnesium, aluminium.
	By (*c*) amalgamation processes....	*e.g.*	silver.

C.—Sulphides.

Single decomposition	By heating with air	*e.g.*	mercury, copper, lead.
	[illegible] introduced the use of the [illegible]metal, etc.	*e.g.*	mercury, antimony, lead.
	[illegible]ed his brother chemists to [illegible] reducing [illegible]earch.	*e.g.*	iron, zinc, antimony.
[illegible] composition	[illegible]ing into chloride and treating as above	*e.g.*	silver.

D.—Carbonates.

Single decomposition...	By heating with carbon.....	*e.g.*	zinc, sodium, potassium.
Double decomposition followed by single decomposition	By roasting to oxide and reducing as above.....	*e.g.*	iron.
	By converting into chloride and treating as above	*e.g.*	copper.

III.—*COMPLEX ORES;* i. e., *containing more than one metal.*

I. Alloy extracted by some or other process, as above....		*e.g.*	silver-lead alloy, spiegeleisen.
II. Special processes adopted for extraction of metals separately.....		*e.g.*	cupriferous pyrites.

Descriptions of some of these methods are given in those chapters relating to the several metals.

Fluxes are used in nearly all of the metallurgical processes, and their characteristics are determined by the special requirements of each case.

Fluxes are, as the name (from *fluo*, to flow) indicates, substances which assist in reducing the solid materials in the smelting furnace to the liquid state, forming a compound known as slag, or sometimes as cinder.

It frequently happens that two substances, having a powerful affinity for each other, will unite chemically, when brought in contact, and fuse into a new compound at a much lower temperature than that at which either will melt alone.

Silica fuses only at an extremely high temperature, if isolated, or if heated in contact with bodies for which it has no affinity; but, if mixed with an alkali, as potash, soda, or lime, the mixture fuses readily. The two first-named alkalies are too expensive for general use in metallurgy; but the latter is plentifully distributed, as a carbonate, and it is, therefore, the flux generally used in removing silica from ores, by fusion.

Borax similarly unites with oxide of iron to produce a readily fusible glass; and it is, therefore, often used by the blacksmith as a *flux* when welding iron.

Quartz sand is also used by the blacksmith for precisely the same purpose. Being composed almost purely of silicic acid, it forms a readily fusible silicate with the oxides of iron, and it is used wherever the mass of iron is of considerable size, and is capable of bearing, without injury, the high temperature necessary for its fusion.

Fluor-spar, a native fluoride of calcium, has been frequently and extensively used as a flux. Its name was given to it in consequence of that fact. It is a very valuable fluxing material, and is used where the expense of obtaining it does not forbid its application. It has special advantages arising from the fact that it is composed of two elements, both of which perform an active and a useful part in the removal of the non-metallic constituents of ores. In the removal of sulphur

and phosphorus from iron, it also possesses the great advantage that the resulting compounds produced by its union with those elements are gaseous, and pass off up the chimney, instead of remaining either solid or liquid in the furnace and contaminating the iron by their contact.

Since the aim, in selecting a flux, is usually to form, with the impurities to be removed, a readily fusible glass, such materials are selected, in each case, as are found, by analysis or by trial, to unite in those proportions which produce such a compound.

The "*slag*" thus formed should usually be a compound silicate of lime and alumina, as free as possible from refractory substances, like magnesia, and from the oxides of the metal treated.

The flux used, therefore, where an ore contains excess of silex, is a mixture of lime and alumina—as, for example, limestone and clay.

Where the ore already contains alumina, limestone only may be needed. In the reduction of iron ores, limestone is very generally the only material added as a flux.

The Fuels used in engineering and metallurgy are considered very fully in special treatises (see Mat. of Eng.).

Mechanical Processes. — Metallurgy includes both mechanical and chemical processes. The former consist in crushing and washing ores, or the gangue with which they are associated, to render the processes of reduction or of separation more easy, complete, and economical. The "stone-breaker," or "rock-crusher," is the form of crushing apparatus used for breaking rock into pieces of fixed size. It often consists of an arrangement of vibrating jaw, *J* (Fig. 1), hung from the centre, *K*, and operated by a knee-joint, *GEG*, the connecting-rod of which, *E*, is raised and depressed by a crank, *C*, driven by a steam engine. A fly-wheel, *B*, gives regularity of motion, and stores energy needed at the instant when the squeeze occurs. Steel or cast-iron faces, *PP*, receive the wear. The breadth of opening at *I*, which determines the maximum size of pieces crushed, is adjusted by a wedge at *OW*, set by a screw at *N*. The jaw is pulled back

by a spring *R*. Many modifications of this, the Blake crusher, are now made.

Stamps consist of heavy weights carried at the ends of vertical rods, which are lifted either by cams on a continuously revolving shaft, or by the action of a steam piston. The former are the older, and for many kinds of work the most effective style; the latter are, however, found vastly more economical for other cases, as in the crushing of some of the copper-bearing rock of the Lake Superior district.

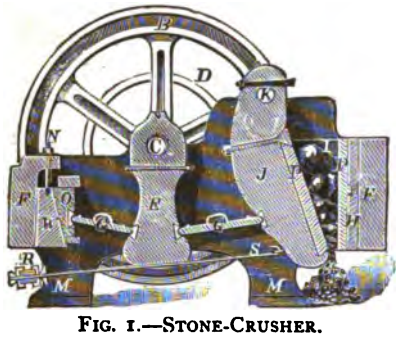


FIG. 1.—STONE-CRUSHER.

Washing machinery is largely used in silver mining and reduction, and less generally in working the ores of the "useful" metals. It takes many forms, according to the kind of work to be done; this is usually the washing of earthy matter from harder ores or the separation of heavy masses from an earthy mass in which it is imbedded.

The Working of Metals, as an art, antedated, unquestionably, the very earliest historic periods, and introduced the "age of bronze." The first metal-work was done in gold, silver, copper, bronze, brass, lead, and iron, and possibly tin. The East Indians, the Egyptians, the early Greeks, and perhaps other nations, were familiar with methods of working these metals and alloys, and are said to have been conversant with a now unknown art of hardening and tempering bronze, to give cutting edges on knives and weapons, which were only equalled by those of steel. Copper was much used during the Middle Ages, and from A.D. 1100 to 1500 especially, for a great variety of objects. Bronze was the most common material for works in art among the older nations.

The metals were worked both by casting and by the "*repoussé*" method. The earliest castings were solid, and the art of economizing cost and weight by "coring out" the inner portions was one of later introduction. The first

"cores" in bronzes were of iron, and were left in in the casting; still later, removable clay and wax cores were used.

The finest Greek art-castings and those of the Romans, and later the Italian artists, were made by the method called, by French workers in bronze, that "*à cire perduc.*" The statue or other object was first roughly modelled in clay, and in size slightly less than that proposed for the finished piece. On this clay model was laid a coating of wax, which was worked to exactly the intended finished size and form, and was frequently even given the smoothness of surface desired in the finished casting; this formed a thin skin over the clay. A clay, or earthy, wash was next applied, covering the wax surface, and over this was placed a thick and strong mass of clay, worked on in soft state and allowed to dry and set. The whole was then baked slowly; the wax melted and flowed out from between the two masses of clay, leaving a space into which molten bronze was finally poured to form the casting. The two parts of the clay mould were secured together by stays of bronze which were built, or afterward driven, into both parts, and thus connected them together. When the casting had cooled, the clay was torn away from the outside and removed from the interior of the bronze; the surface was finished up as required, and the work was done. The finest antique bronzes were thus made.

The hammered, or "*repoussé*," work of the Greeks was wonderfully perfect at a date which is supposed to have been earlier than that of their large castings. The first efforts in this direction were rude; the sheet metal was hammered into shape over blocks of wood, which had been roughly given the desired form. Later, a bed of pitch, or of soft kinds of cement, was prepared, and the sheets hammered into form by striking them on the back side, the bed yielding to the blow and thus allowing the metal to assume the desired shape without being broken by the hammer or by the punch used. The work was often reversed and the final finish given on the front side. This method produced some of the largest and the finest of the ancient Asiatic bronzes, and fine work in gold, silver, and copper. The Greeks excelled in this

method of metal-working. In many cases, the thickness of the metal was reduced nearly to that of paper, without injury to its surface. The Siris bronzes of about B.C. 400 are of this kind.

Tin was probably worked into vessels for domestic use by the natives of Cornwall before the settlement of the country by the Romans. Lead was used throughout Europe, in the mediæval period, in sheets for roof-coverings, and cast into objects of complicated form. Specimens remain of the former, exhibiting its great durability when exposed to the weather.

Like the modern Chinese and Japanese artists, the ancient workers in metal used gold and silver to adorn and give relief to their castings in bronze. Mirrors, of fine surface and thus ornamented, are common among collections of the products of Greek art. The bronzes of the Italian artists of the Middle Ages are remarkable for their beauty as art work in metal, as well as for their beauty of design; even their work in iron is famous for its unexcelled beauty and the skill exhibited in forging it. Modern work has not equalled that of the Middle Ages, or even that of the early Greeks.

Metal is the name applied to above fifty of the chemical elements. The larger number of the metals are but little known, and many are found in such extremely minute quantities, that we are not well acquainted with either their chemical or their physical characteristics. Some approach the non-metallic elements so nearly in their properties, that they are placed, sometimes in the one class, and sometimes in the other. Very few of the metals are well fitted for use in construction; but, fortunately, those few are comparatively widely distributed, and are readily reduced from their oxides or sulphides, in which states of combination they are almost invariably found in nature.

The "Useful Metals" are iron—in its various forms of cast iron, malleable or wrought iron, and steel—copper, lead, tin, zinc, antimony, bismuth and nickel, and occasionally aluminium and rarer metals are used for similar purposes.

From this list of metals, and from their alloys, the engi-

neer can almost invariably obtain precisely the quality of material which he requires in construction. He finds here substances that exceed the stones in strength, in durability under the ordinary conditions of mechanical wear, and in the readiness and firmness with which they may be united. They are superior to timber of the best varieties in strength, hardness, elasticity and resilience, and have, in addition, the important advantages, that they may be given any desired form without sacrificing strength, and may be united readily and firmly to resist any kind of stress.

By proper selection or combination, the engineer may secure any desired strength, from that of lead, at the lower, to the immense tenacity of tempered steel, at the upper limit. He obtains any degree of hardness, or fusibility, and almost any desired immunity from injury by natural destroying agencies. Elasticity, toughness, density, resonance, and varying shades of color, smoothness, or lustre, may also be secured.

The Laws Governing Distribution of the Ores of the metals are comprehended in the science of geology. The detection of their presence in any locality, and bringing them to the surface of the ground, free from the foreign earthy substances which accompany them, is the work of the mining engineer, and of the miner. The "reduction" of the metals from ores, by chemical and mechanical processes, constitutes the business of the metallurgist. The engineer takes the metals as they are brought into the market, and makes use of them in the construction of permanent or movable structures.

The Requirements of the Engineer include some acquaintance with the general principles, and with the experimental knowledge, which are to be obtained by the study of geology, of mining, and of metallurgy, to aid him in selecting the metals used in his constructions; since their qualities cannot always be determined by simple inspection, and it is not always possible to subject them to such tests as he may consider desirable before purchasing. In such cases, a knowledge of the localities whence the ores were obtained.

familiarity with the processes of manufacture, and with the nature of the materials employed by the metallurgist, coupled with a knowledge of the effects of various foreign substances upon the quality of the metal, may enable the engineer to judge with some accuracy what metal will best suit his purposes, and what will be likely to prove valueless. He is also thus enabled to judge, should the purchased material prove defective, where the defect in quality originated, and to place the responsibility where it belongs.

The student will seek this knowledge in special works on geology and metallurgy. But brief reference can be made to these subjects here.

All the metals possess, as a whole, a number of properties which define the class, although few of these properties are common to all. The metals all unite chemically with oxygen to form basic oxides, and some of them take higher proportions of oxygen, forming acids. All metals are capable of similarly uniting with chlorine. All are capable of fusion and liquefaction at certain temperatures, fixed for each, which are usually high. Mercury, however, is liquid at ordinary temperatures. The metals are also capable of vaporization, and their vapors have some physical characteristics quite different from those of the solid metal. Thus, silver, white when solid or liquid, becomes blue as a vapor; mercury vapor is colorless, potassium is green. All are opaque, except in exceedingly thin films, when some become apparently translucent. Gold transmits green light, mercury blue, and silver remains opaque in the thinnest leaf yet made.

The Special Qualities of the Useful Metals which give them their importance as materials of construction are: their *strength*, *hardness*, *density*, *ductility*, *malleability*, *fusibility*, *lustre*, and *conductivity*.

Strength, or the resistance offered to distortion and fracture, is their most valuable quality. The strength of metals and alloys in general use has been very carefully determined by experiment, and will be given hereafter.

Of the metals in our list, lead is the least tenacious, and steel is the strongest.

The Non-Ferrous Metals, which are to-day of comparatively little importance to the engineer in the construction of machines or of structures, and which have been so generally superseded by iron and steel in every department of art, were, in earlier times, in some cases, as copper, tin, lead, the most common materials of construction. The three just mentioned were known in prehistoric times, and the Greeks were also familiar with mercury, as well as with iron. Valentinus discovered and described antimony in the 15th century, and bismuth and zinc became known at about the same time or a little later. Brande discovered arsenic and cobalt about the middle of the 18th century, and Ward discovered cobalt.* Cronstedt discovered nickel and Scheele manganese in 1774, and tungsten was prepared in 1783 by the brothers D'Elhujart. Palladium, rhodium, iridium and osmium were isolated and described by Wollaston and others in 1803. The alkaline earths, recognized as oxides by Davy in 1807–8, were soon after deoxidized, and potassium and sodium became known. Aluminium and magnesium were separated in 1828 and 1829, respectively by Wöhler and by Bussy, and cadmium had already been discovered by Stromeyer in 1818. The rarer and more unfamiliar metallic elements were found later. The properties of these metals have been referred to in a general way in an abridged account of them given in Part II. of this work. A more detailed account of those used in construction will occupy the greater part of this volume. The following is a *resumé* of the general characteristics of these metals.

The Relative Tenacities are approximately as below, lead being taken as the standard.

RELATIVE TENACITIES OF METALS.

Lead	1.0	Cast iron	7 to 12
Tin	1.3	Wrought iron	20 to 40
Zinc	2.0	Steel	40 to 100
Worked copper	12 to 20		

* Encyclopædia Britannica, 1883, art. Metals.

No two pieces of metal, even nominally of the same grade, have precisely the same strength. The figures can therefore only represent approximate ratios, as every variation of purity, structure, or even of temperature, is found to affect their strength.

Cast metal is usually weaker than the same metal after having passed through the rolls or under the hammer; those which can be drawn into wire are still more considerably strengthened by that process. Metals are stronger at ordinary temperatures than when highly heated, and "annealing" is found to reduce the strength of iron and steel, although frequently increasing their ductility, and produces an opposite effect on copper and its alloys. "Hardening," produces the contrary effect. The presence of impurities and the formation of alloys produce changes of strength, sometimes increasing, sometimes diminishing it.

Copper alloyed with tin or zinc, in certain proportions, is strengthened; and the addition of a small percentage of phosphorus to the alloy has a marked effect in increasing its tenacity and ductility.

Hardness varies in the metals as considerably as their tenacity, and, like the latter quality, is greatly influenced in the same metal by very slight changes, either physical or chemical.

Thus metals are hardened by cold hammering and softened by sudden change of temperature. The addition of scarcely more than a trace of impurity often produces a marked change in the degree of hardness of metals.

The scale of hardness, according to Gollner,* is as follows:

Soft lead	1	Cast iron	10–11
Tin	2	Mild steel	12–13
Hard lead	3	Tool " blue	14
Copper	4–5	" " violet	15
Alloy for bearings (C., 85; T., 10; Z., 5)	6	" " straw	16
Soft cast iron	7	Hard bearings (C., 83; Z., 17)	17
Wrought iron	8	Very hard steel	18

* Tech. Blaetter; London Engineering, June 1, 1883, p. 519.

The hardness of metals, as determined by Dumas, is exhibited in the following table of their order.

HARDNESS OF THE METALS.

Titanium	Scratch steel.	Chromium	Scratch glass.
Manganese		Rhodium	
Platinum		Nickel	
Palladium		Cobalt	
Copper		Iron	Scratched by glass.
Gold	Scratched by Calc Spar.	Antimony	
Silver		Zinc	
Tellurium		Lead	Scratched by the nail.
Bismuth		Potassium	Soft as wax.
Cadmium		Sodium	
Tin		Mercury,	Liquid.

Conductivity, or their power of transmitting molecular vibrations of either heat or electricity, is another property of the metals, upon which is founded many useful applications.

Of the "useful" metals, copper has by far the highest conductivity, and is only second in this respect to gold and silver, the best known conductors. Its conductivity is greatly reduced by the presence of foreign substances.

The powers of conduction for heat and electricity seem to have very similar relative values. Conductivity is reduced by increase of temperature and by presence of impurities.

The following table of relative conductivities was determined by the experiments of Despretz, and very closely confirmed by Forbes.

RELATIVE THERMAL CONDUCTIVITIES OF METALS.

Gold	1,000	Zinc	360
Silver	973	Tin	304
Copper	878	Lead	180
Iron	374	Marble	25

The *electric conductivities* obtained by Becquerel, and the

thermal conductivities given by Wiedmann and Franz, are as below: *

CONDUCTIVITIES OF METALS.

	Electric.	Thermal.	
		In Vacuo.	In Air.
Silver	1,000	1,000	1,000
Copper	....	....	....
" commercial	915	748	736
Gold	649	548	532
Brass	....	240	236
Tin	140	154	145
Platinum	79·3	84	840
Lead	82.7	79	85
Bismuth	....	....	18

The resistance to the voltaic current has been found by Mr. K. Hedges † as follows, wire and foil being used, and strength of the current so adjusted that on increasing it 20 per cent. the metal would fuse. The experiments continued 24 hours and the temperature was 69° F. (21° C.)

RESISTANCES OF METALS TO ELECTRIC CURRENTS.

Metal.	Resistances as Measured.	
	Before Heating.	Change in 24 Hours.
1. Commercial tin, wire	0.815 Ohms.	— 0.003
2. Lead, soft	0.835 "	— 0.005
3. Copper, soft	0.810 "	+ 0.000
4. Tin-foil, pure	0.860 "	+ 0.000
5. Tin and lead	0.800 "	— 0.160
6. Aluminium ("Albo") alloy, foil	0.835 "	+ 0 000
7. Aluminium and tin	0.820 "	+ 0.0008

* Part II., p. 8, § 10.

† Brit. Assoc. Reports, 1883, Sec. G.

Commercial copper (Rio Tinto), has been found to have, in some cases, but one-seventh the conductivity of pure copper.

Conductivity is reduced by increase of temperature, according to Forbes, and at rates varying with the character of the metal.

M. Benoit has measured the electrical resistance of various metals at temperatures from 0° to 860° C. The mean of the figures obtained is given in the following table, the second column giving the resistance in ohms of a wire 39.37 inches (1 metre) long, and having a cross section of 0.03 inch (0.2 sq. cm.), and column three the same quantity in Siemens units. Column four gives the resistance compared with silver:

METAL.	OHMS.	SIEMENS.	
Silver, A	.0154	.0161	100
Copper, A	.0171	.0179	90
Silver, A.(1)	.0193	.0201	80
Gold, A	.0217	.0227	71
Aluminium, A	.0309	.0324	49.7
Magnesium, H	.0423	.0443	36.4
Zinc, A., at 350°	.0565	.0591	27.5
Zinc, H	.0594	.0621	25.9
Cadmium, H	.0685	.0716	22.5
Brass, A. (2)	.0691	.0723	22.3
Steel, A	.1099	.1149	14
Tin	.1161	.1214	13.3
Aluminium bronze, A. (3)	.1189	.1243	13
Iron, A	.1216	.1272	12.7
Palladium, A	.1384	.1447	11.1
Platinum, A	.1575	.1647	9.77
Thallium	.1831	.1914	8.41
Lead	.1985	.2075	77.60
German silver, A. (4)	.2654	.2775	5.80
Mercury	.9564	1.0000	1.61

A, annealed; H. hardened; (1) silver .75; (2) copper 64.2, zinc 33.1, lead 0.4, tin 0.4; (3) copper 90, aluminium 10; (4) copper 50, nickel 25, zinc 25.

These results, are all taken at 0° C., and agree closely with those obtained by other observers. The resistance increases regularly for all metals up to their points of fusion. This

increase, however, differs for different metals. Tin, thallium, cadmium, zinc, lead, are found to vary similarly; at 200° to 230° their resistance has doubled. The resistance of iron and steel doubles at 180°, quadruples at 430°, and at 860° is about nine times that at 0°. Palladium and platinum increase much less, their resistance becoming twice that at 0° C., at 400° to 450°. Gold, copper, and silver form an intermediate group. In general conductibility decreases more rapidly the lower its point of fusion. Iron and steel are exceptions to this rule. In alloys the variation is less than in their constituents, and this is especially the case with German silver.

The thermal conductivity of brass was found by Isherwood to be 556.8 thermal units (British) per hour per square foot and per 1° Fahr., and to vary at the difference of temperature.

Silicon-bronze may be given a conductivity but little less than that of copper, but its tenacity then diminishes considerably; that having 95 per cent. the conductivity of copper, has but one half the strength of that of which the conductivity is 25 per cent.

The Lustre of these metals is measured by their power of reflecting light. Thus, according to Jamin, silver may reflect 0.9 of the light sent between surfaces of mirrors made of that metal; after ten normal reflections it yields from 0.24 to 0.48, the former figure being that for violet, and the latter for red light. The figures for speculum metal are 0.6 to 0.7, 0.006 and 0.035; those for steel, 0.6, 0.006, and 0.007.

Estimating weights of metal in various forms as used by the engineer is a simple operation. Thus: if

d = diameter of a circular section, or the minor diameter of an ellipse;
d' = major diameter of ellipse;
l = length of piece, section uniform;
b = breadth;
k = a constant;
W = total weight.

The weight of any piece of uniform section is

$$W = kd^2l \text{ for cylindrical bars;}$$
$$= kdd'l \text{ " elliptical sections;}$$
$$= kbdl \text{ " rectangular sections.}$$

The values of k when l is in feet, other dimensions in inches and W in pounds, are

VALUES OF k IN

	$W = kdd'l.$	$W = kbdl.$
Brass, sheet	2.906	3.700
Iron, wrought	2.618	3.333
Lead, sheet	3.888	4.950
Steel, soft	2.670	3.400

For pipes, $W = k(d_2^2 - d_1^2)$ when $d_1 d_2$ represent the inner and outside diameters in inches.

To obtain weights in kilogrammes when measures are in centimeters, multiply the above by 0.00241.

The " metallic lustre " is a property of the metals almost peculiar to them, and constitutes one of their marked characteristics.

Polished steel, and an alloy of copper and tin known as *speculum metal*, burnished copper and aluminium, as well as the precious metals, gold and silver, exhibit this beautiful and peculiar lustre very strikingly.

Tin, lead, and zinc, are lustrous, but they are not capable of taking a sufficiently high polish to exhibit this quality in such a degree as the metals first named.

The Specific Gravities of the commercial metals are as follows:

THE DENSITIES OF PURE METALS according to Fownes,* are

* Chemistry, 10th ed., p. 297.

SPECIFIC GRAVITIES OF PURE METALS.

(Water at 60° F. (15.5 C.) = 1.)

Platinum	21.50	Cobalt	8.54
Iridium	21.15	Manganese	8.00
Gold	19.50	Iron	7.79
Tungsten	17.60	Tin	7.29
Mercury	13.59	Zinc	7.10
Palladium	11.80	Antimony	6.80
Lead	11.45	Tellurium	6.11
Silver	10.50	Arsenic	5.88
Bismuth	9.90	Aluminium	2.67
Copper	8.96	Magnesium	1.75
Nickel	8.80	Sodium	0.97
Cadmium	8.70	Potassium	0.87
Molybdenum	8.63	Lithium	0.59

For the purposes of the engineer, the densities and the weights per unit of volume of commercial materials are the data desired. The following table gives such a set of figures. As is seen by comparing the tables, authorities differ somewhat in these figures.

WEIGHTS AND DENSITIES OF COMMERCIAL METALS.

NAME.	S. G.	LBS. IN CU. FT.	KILOG'S IN CU. M.
Aluminium, cast	2.56	160	2,560
" sheet	2.67	167	2,670
Antimony, cast	6.7	418	6,700
Bismuth, "	9.8	614	9,800
Brass,* cast	8.4	525	8,400
" sheet	8.5	532	8,500
" wire	8.54	533	8,540
Bronze * (ordinary)	8.4	524	8,400
Copper,* bolts	8.85	548	8,850
" cast	8.60	537	8,600
" sheet	8.88	549	8,800
" wire	8.88	550	8,800
Gold, hammered	19.4	1,205	19,400
" standard	17.65	1,103	17,650
Gun metal (bronze)	8.153	510	8,153

NAME.	S. G.	LBS. IN CU. FT.	KILOG'S IN CU. M.
Iron, cast, from	6.955	435	6,955
" " to	7.295	456	7,295
" " average	7.125	445	7,125
" wrought, from	7.560	473	7,560
" " to	7.800	488	7,800
" " average	7.680	480	7,680
Lead, cast	11.352	710	11,352
" sheet	11.4	712	11,400
Mercury, fluid	13.6	848	13,600
" solid	15.632	977	15,632
Nickel, cast	7.807	488	7,807
Pewter	11.600	725	11,600
Platinum, mass	19.550	1,219	19,500
" sheet	20.337	1,271	20,337
Silver, mass	10.5	655	10,500
" standard	10.534	658	10,534
Steel, hard	7.82	496	7,820
" soft	7.834	491	7,834
Tin,* cast	7.3	456	7,300
Type metal, cast	10.450	653	10,450
Zinc,* cast	7.03	439	7,030
" sheet	7.29	456	7,290

Ductility and Malleability are properties of the metals scarcely less important to the engineer than that of tenacity. The ductility of a metal or an alloy is its capacity for being drawn out into wire, by being pulled through holes in the wire-drawers' plates, each hole being slightly smaller than the preceding, until the wire reaches a limit of fineness which is determined by the degree of its ductility, and, as well, by the skill of the workman.

Great tenacity, in proportion to the degree of hardness, or high tenacity, a low elastic limit and a certain viscosity, is the combination of qualities required to insure durability.

Gold has been drawn until the wire measured but $\frac{1}{5000}$ inch in diameter, and silver and platinum are nearly as ductile. Iron and copper are the most ductile of the common metals.

* See text later.

The *malleability* of a metal, or the power which it possesses of being rolled into sheets without tearing or breaking, is determined by its relative tenacity and softness.

The malleability of the non-ferrous metals is determined by their plasticity simply, and this quality is observable in all metals having no defined elastic limit. It is also often determined to some extent by the physical condition of the metal; thus zinc, brittle in the ingot, is malleable at the boiling temperature of water, and, if worked at that temperature, becomes permanently malleable in the sheet or the bar. Hardening and tempering are operations which can be performed on many metals with the effect of modifying their malleability and other properties; but while sudden cooling from high temperature hardens steel, it softens copper and the bronzes and brasses. Ductility, being dependent upon tenacity largely, is not as generally observed as malleability.

Gold is the most malleable of all metals, and has been beaten into sheets of which it would require 300,000 to make up a thickness of one inch.

Wrought iron of good quality, and the softer grades of steel, are very malleable; the former has been rolled to less than $\frac{1}{1000}$ of an inch (0.00254 centimetre) thickness. Cast iron and hard steels are neither malleable nor ductile.

Copper is very malleable, as well as ductile, if kept soft by frequent annealing; tin possesses this property, also; and zinc, although quite brittle when cold, becomes malleable at a temperature somewhat exceeding the boiling point of water; its temperature being still further elevated, it again becomes brittle, so much so that it may be powdered in a mortar. Some of the copper-tin alloys exhibit the same peculiarity.

Odor and Taste characterize many metals. Brass, for example, possesses a very marked taste and perceptible odor when applied to the tongue and when rubbed. These qualities may indicate solubility and volatility, but no direct experiment has revealed their precise nature. Many of the lighter metals are quite volatile at moderately high temperature.

Lead can be rolled into quite thin sheets, but it is less malleable than either copper, tin, or the precious metals.

The following is a table of the relative ductility of metals:

ORDER OF DUCTILITY OF METALS.

1. Gold,	4. Iron,	7. Zinc,
2. Silver,	5. Copper,	8. Tin,
3. Platinum,	6. Aluminium,	9. Lead.

In the following list, the metals named are placed in the order of their malleability.

ORDER OF MALLEABILITY OF METALS.

1. Gold,	4. Tin,	7. Zinc,
2. Silver,	5. Platinum,	8. Iron,
3. Copper,	6. Lead,	9. Nickel.

Prechtl gives the following as the order in which the metals stand in this respect :*

MALLEABILITY.		DUCTILITY.
Hammered.	Rolled.	Wire-drawn.
1. Lead,	Gold,	Platinum,
2. Tin,	Silver,	Silver,
3. Gold,	Copper,	Iron,
4. Zinc,	Tin,	Copper,
5. Silver,	Lead,	Gold,
6. Copper,	Zinc,	Zinc,
7. Platinum,	Platinum,	Tin,
8. Iron.	Iron.	Lead.

Authorities differ, however, in their statements in regard to the order of the metals in these respects, and the preceding figures as given in tables are often quoted from Regnault.†

* Encyclopædia Britannica. † Regnault's Chemistry.

The following table of the principal metals and their properties is extracted from Watts:*

CHARACTERISTICS OF METALS.

NAME.	DATE OF DISCOVERY.	NAME OF DISCOVERER.	S. G. Water = 1.	SP. HEAT.	MELTING POINT.	CONDUCTIVITY. Thermal.	CONDUCTIVITY. Elect.
Platinum ...	1741	Wood	21.5	0.0324	.....	8.4	18.
Iridium	1803	Descotils.....	21.15	0.0326	.....	.....	.....
Gold.....	....	.....	19.26	0.0324	1200° C. (?)	53.2	78.
Mercury....	....	.....	15.60	0.0319	−39° C...	.....	.....
Palladium ..	1803	Wollaston.....	11.80	0.0593	.....	6.3	18.4
Lead.....	....	.....	11.33	0.0314	332° C...	8.5	8.3
Silver.....	....	.....	10.57	0.0570	1000° C...	100	100
Bismuth....	....	.....	9.80	0.0308	270° C...	1.8	1.2
Copper.....	....	.....	8.94	0.0952	1200° C. (?)	73.5	99.9
Nickel	1751	Cronstedt	8.82	0.1086	.....	.....	13.1
Manganese..	1774	Gahn; Scheele.	8.02	0.1217	.....	.....	.....
Iron	....	.....	7.84	0.1138	2000° C. (?)	11.9	16.8
Tin.....	....	.....	7.30	0.0562	.....	14.5	12.4
Zinc.....	....	.....	7.13	0.0955	433° C...	.....	29.
Antimony ..	....	.....	6.72	0.0508	450° C...	.....	4.6
Aluminium..	1828	Wöhler	2.56	0.2143	.....	.....	56.1
Magnesium .	1829	Bussey.....	1.74	0.2499	433° C...	.....	41.2

Crystallization is always observed in metal when deposited from solution or when solidifying from fusion when the conditions are favorable. Gold, silver, copper, antimony and bismuth, and many alloys, as those of copper and of iron, are found in crystalline form in nature. Deposition by the voltaic current often produces very large and perfect crystals. Lead is precipitated from solutions in beautiful crystalline forms when displaced by zinc. Iron forms well-defined crystals when kept heated at nearly the temperature of fusion for a considerable time, and is supposed by some authorities to take on the cubic form when exposed to severe and long-continued jarring. This tendency to crystallization is

* Dictionary of Chemistry; Lond., 1868; vol. iii.; p. 936.

increased by the presence of manganese or of phosphorus. Zinc, in the ingot, is often very distinctly crystalline.

The precious metals, aluminium, cobalt, copper, iron, lead and nickel are so nearly amorphous, or if crystalline in structure in their ordinary state, have such small and uniform crystals that they may be considered compact and homogeneous. Antimony, bismuth, manganese, and zinc, and some of their alloys often exhibit distinct crystallization, which may also be produced in all metals by prolonged heating or slow cooling, and, as supposed by some observers, by long-continued vibration or jarring.

Specific Heats.—The effect of heat upon metallic substances in the production of changes of volume and of temperature varies considerably.

The *Specific Heats* of a number are given as follow: they measure in thermal units the quantity of heat required to change the temperature of a pound or a kilogramme of the metal one degree.

SPECIFIC HEATS OF METALS.

	SPECIFIC HEAT.	AUTHORITY.
Wrought iron	.1138	Regnault.
" 32—212 F.	.1098	Dulong & Petit.
" 32—392 F.	.1150	"
" 32—572 F.	.1218	"
" 32—662 F.	.1255	"
Cast iron	.1298	Regnault.
Steel, soft	.1165	"
" tempered	.1175	"
Copper	.09515	"
" 32—212 F.	.0927	Dulong & Petit.
" 32—572 F.	.1013	"
Cobalt	.10696	Regnault.
" carburetted	.11714	"
Nickel	.1086	"
" carburetted	.1119	"
Tin, English	.05695	"
" Indian	.05623	"
Zinc	.09555	"
" 32—212 F	.0927	Dulong & Petit.
" 32—572 F	.1015	"

	SPECIFIC HEAT.	AUTHORITY.
Brass	.0939	Regnault.
Lead	.0314	"
Platinum, sheet	.03243	"
" 32—212 F	.0335	Dulong & Petit.
" at 572 F	.03434	Pouillet.
" " 932 F	.03518	"
" " 1832 F	.03718	"
" " 2192 F	.03818	"
Mercury, solid	.0319	Regnault.
" liquid	.03332	"
" 32—212 F	.033	Dulong & Petit.
" 32—572 F	.035	"
Antimony	.05077	Regnault.
" 32—572 F	.0547	Dulong & Petit.
Bismuth	.03084	Regnault.
Gold	.03244	"
Silver	.05701	"
" 32—572 F	.0611	Dulong & Petit.
Manganese	.14411	Regnault.
Iridium	.1887	"
Tungsten	.03636	"

The following table exhibits the relationship between the combining numbers and specific heats of the metals; the product of specific heat and of combining number is seen to be very nearly constant, as shown by Kopp, who also makes this product, or the "atomic specific heat," 6.4 for 42 elements, including all in this table. Kopp also verifies the law of Woestyn and Garnier, finding the specific heat of the molecule equal to the sum of the specific heats of the constituent atoms.

SPECIFIC HEATS AND COMBINING NUMBERS.

METALS.	COMBINING NUMBERS.	SPECIFIC HEAT (REGNAULT).	PRODUCT.
Aluminium	27	0.2143	5.8
Antimony	122	0.0508	6.1
Arsenic	75	0.0814	6.1
Bismuth	210	0.0308	6.5
Cadmium	112	0.0567	6.3
Copper	63.5	0.0951	6.0
Gold	196	0.0324	6.4
Lead	207	0.0314	6.4
Iron	56	0.1138	6.1
Magnesium	24	0.2499	6.0
Manganese	55	0.1217	6.7
Mercury (solid)	200	0.325	6.5
Nickel	59	0.1089	6.4
Palladium	106	0.0593	6.3
Platinum	197.6	0.0329	6.5
Potassium	39.1	0.1695	6.5
Silver	108	0.0570	6.2
Sodium	23	0.2934	6.7
Tin	118	0.0562	6.6
Zinc	65	0.0956	6.2

The specific heats are slightly variable with change of temperature. This change has been carefully studied only in a few cases. Holman deduces,* by collating results of experiments published by known authorities, for the specific heat of iron:

$$\left.\begin{aligned} k &= 0.10687 + 0.0000304(t^\circ - 32) + 0.000000238(t - 32)^2 \\ k &= 0.10687 + 0.0000547t + 0.0000000428t^2 \end{aligned}\right\}$$

for the Fahrenheit and Centigrade scales respectively.

For platinum he obtains:

$$k = 0.0328 + 0.00000302(t - 32) + 0.000000000009(t - 32)^2,$$
$$k = 0.0328 + 0.0000544t + 0.000000000016t^2,$$

or, very nearly,

$$\left.\begin{aligned} k &= 0.03208 + 0.00000304\,(t - 32) \\ k &= 0.03208 + 0.0000547t \end{aligned}\right\}$$

* *Journal Franklin Institute*, August, 1882.

The figures given on pp. 27, 28, are mean values between the temperatures of freezing and of boiling, of the quantity of heat, in thermal units, required to produce a change of temperature of one degree. Their values have been shown by Dulong and Petit to increase with the rise of temperature, as does the specific heat of water itself. When melted their specific heats are greater than when solid.

The specific heats represent the number of units of water which would be raised in temperature one degree by the addition of the amount of heat which would raise one unit of weight of the metal one degree. Specific heat is sometimes called "Capacity for heat."

The Expansion of the Metals by increase of temperature is exhibited by the following table of *coefficients of linear expansion.*

The figures represent the extension, in parts of its own length, of a bar of the given metal during a rise in temperature from the freezing to the boiling point of water.

LINEAR EXPANSIONS OF SOLIDS.

	EXPANSION BETWEEN 32°F.(0°C.) AND 212°F.(100°C.)	AUTHORITY.
Glass	0.000872 to 0.000918	Lavoisier and Laplace.
"	0.000776 to 0.000808	Roy and Ramsden.
Copper	0.001712 to 0.001722	Lavoisier and Laplace.
Brass	0.001867 to 0.001890	" "
"	0.001855 to 0.001895	Roy and Ramsden.
Iron	0.001220 to 0.001235	Lavoisier and Laplace.
Steel (untempered)	0.001079 to 0.001080	" "
" (tempered)	0.001240	" "
Cast Iron	0.001109	Roy and Ramsden.
Lead	0.002849	Lavoisier and Laplace.
Tin	0.001938 to 0.002173	" "
Silver (fine)	0.001909 to 0.001910	" "
Gold	0.001466 to 0.001552	" "
Platinum	0.000884	Dulong and Petit.
Zinc	0.002976	Daniell.

The coefficients of cubical expansion are obtained by multiplying those of linear expansion by three.

The freezing point being assumed as a standard of temperature, in these applications we may determine readily the density of a metal at any other temperature, since the density will vary inversely as the volume.

If the volume at standard temperature be 1, and A the coefficient of cubical expansion, we may construct a formula to determine the density D' at any given temperature; it will be as follows:

$$D' = \frac{D(1 + At)}{1 + At'}$$

Alloys usually have coefficients of expansion nearly equal to a mean of the coefficients of the metals composing them.

Applications of the Principles just stated are met with very frequently in the arts; and the engineer constantly finds occasions arising on which he must keep the effects of change of temperature carefully provided for.

Steam pipes are fitted with expansion-joints. Castings are given proportions quite different, frequently, from those dictated by the consideration simply of the laws of resistance to mechanical force. In laying railroad track the rails are, in cold weather, placed with a considerable space between their ends, to allow for expansion under the heats of summer. Grate bars are fitted loosely into their places to allow for their expansion after the fire has been started.

The Force with which Contraction or Expansion takes place is, within ordinary ranges of temperature, proportioned to the extent of the range.

Barlow's experiments indicated that a bar of iron might be stretched $\frac{1}{10000}$ of its length for each ton (1,016 kilogrammes) of stress per square inch of section. This increase of length is produced by a change of temperature of 16° Fahr. (9° Cent.). A pound of iron undergoing a change of temperature of 180° Fahr. (82° Cent.), increases about $\frac{1}{240}$ in volume, and is capable of doing 16,000 foot pounds (2,212 kilogramme-metres) of work by the expenditure of this heat.

It sometimes becomes necessary, in designing bridges and other constructions, to calculate with care the probable magnitude and effects of forces arising from changes of temperature, where parts are confined, as well as in the amount of change in dimensions with change of temperature, when they are not rigidly fixed.

In estimating strains arising from expansion and contraction with changes of temperature, it is advisable to base the calculations, if possible, upon experimental determinations of the elasticity and of the expansion of the metal which it is proposed to use, since the various grades of the same metal often differ considerably in both expansibility and extensibility. Such calculations will be given in the chapters on strength of iron and steel.

Many cases occur in which it is impossible to estimate, even approximately, the magnitude of forces brought into action by changes of form due to alteration of temperature.

In some cases these forces will be liable to produce rupture, whatever the amount of metal introduced to meet the stress, and increasing the size of parts only renders it more certain that fracture will take place. This is especially true of castings made in brittle and inelastic metal, as ordinary cast iron. Glass vessels for laboratories, and the water-gauge glasses for steam boilers, are purposely made thin to enable them to meet safely sudden and local changes of temperature. Such forces are frequently important elements of weakness in structures. Explosions of steam boilers have occurred in consequence of strains produced by unequal expansion of portions subjected to varying temperatures; and new designs for boilers should always be examined with the greatest care to determine whether such injury can occur. These effects of heat upon the metal must, therefore, be carefully studied while designing parts of machinery or other structures intended to be made of cast iron, or of hard bronze, or brass, and with special care when of large size.

Chaney gives* the following values of the coefficients of linear expansion, at ordinary temperature, as recalculated by him, and corrected for the author, from selected data, for the Standards Office of the British Board of Trade.

EXPANSIONS OF SOLIDS.

	For 1° F.	For 1° C.	Authority.
Aluminium, cast	0.00001234	0.00002221	Fizeau.
" cryst	0.00000627	0.00001129	"
Brass, cast	0.00000957	0.00001722	Sheepshanks
" plate	0.00001052	0.00001894	Ramsden.
" sheet	0.00000306	0.00000550	Kater.
Bronze, Baileys, Cop., 17; tin, 25; zinc, 1.	0.00000986	0.00001774	Clarke.
Same	0.00000975	0.00001775	Hilgard.
Copper	0.00000887	0.00001596	Fizeau.
Gold	0.00000786	0.00001415	Chandler & Roberts.
Iridium	0.00000356	0.00000641	Fizeau.
Lead	0.00001571	0.00002828	"
Mercury (cubic expan.)	0.00009984	0.00017971	Regnault & Miller.
Nickel	0.00004695	0.00001251	Fizeau.
Osmium	0.00000317	0.00000570	"
Palladium	0.00000556	0.00001000	Wollaston.
Pewter	0.00001129	0.00002033	Daniell.
Platinum	0.00000479	0.00000863	Fizeau.
" 90; iridium, 10	0.00000476	0.00000857	"
" 85; " 15	0.00000453	0.00000815	"
Silver	0.00001079	0.00001943	Chandler & Roberts.
Tin	0.00001163	0.00002094	Fizeau.
Zinc	0.00001407	0.00002532	Baeyer.
" 8, tin 1	0.00001496	0.00002692	Smeaton.

These coefficients are not absolutely constant, but vary with the physical conditions of the metals. They are not the same with the same material in its forms of cast, rolled, hammered, hardened, or annealed metal. The value of the coefficient of expansion also increases slightly with increase of temperature.

To determine the length, L', of a bar at any given temperature, t', knowing its length, L, at any other temperature, t, we have the formulas:

* Calculations of densities and expansions; report by the Board of Trade; printed for the House of Commons, London, 1883.

$$L' = \frac{L\left(1 + \frac{at'}{180}\right)}{1 + \frac{at}{180}}, \text{ for Fahr. scale,}$$

$$L' = \frac{L\left(1 + \frac{at'}{100}\right)}{1 + \frac{at}{100}}, \text{ for Cent. scale,}$$

where a is the coefficient given above.

EXPANSIONS OF VOLUME.

	PER DEGREE CENT.*	0° C. (32° F.) to 100° C. (212° F.).
Glass	.00002 to .00003	.002 to .003
Iron	.000035 to .000044	.0035 to .0044
Copper	.000052 to .000057	.0052 to .0057
Platinum	.000026 to .000029	.0026 to .0029
Lead	.000084 to .000089	.0084 to .0089
Tin	.000058 to .000069	.0059 to .0069
Zinc	.000087 to .000090	.0087 to .0090
Brass	.000053 to .000056	.0053 to .0056
Steel	.000032 to .000042	.0032 to .0042
Cast Iron .....about	.000033	.0033

These results are partly from direct observation, and partly calculated from observed linear expansion, which is one-third the cubical expansion.

The Fusibility of the Metals, or their property of becoming liquid at a temperature which is always the same for the same metal, is a quality which has an important bearing upon their useful applications in the arts.

All solids which do not undergo decomposition by heat before reaching that temperature have definite "melting points."

The metals differ more widely in their temperatures of

* Abridged from Watts's "Dictionary of Chemistry."

fusion than even in density. Solidified mercury melts at nearly 40° below zero, Fahr. (− 40° Cent.); while platinum requires the highest temperature attainable with the oxy-hydrogen blow-pipe. The more common metals fuse at temperatures quite readily attainable, although none of them melt at temperatures approaching those ordinarily met with in nature.

Some of the metals may even be readily volatilized, and probably all are vaporized, to a slight degree at least, at very high temperatures. Mercury boils at 330° Cent. (626° Fahr.). Zinc can be distilled at a bright red heat, and copper and gold are known to give off minute quantities of vapor at temperatures frequently occurring during the process of manufacture.

The low temperatures of fusion of tin, lead, bismuth, and antimony, allow of their being readily applied as solders, either alloyed or separately. Cast iron, copper and its alloys, and other metals, melt at temperatures which are easily reached, and the iron and the brass founders are thus enabled by the process of moulding and casting, to produce the most intricate forms readily and cheaply, and thus, when desired, to obtain large numbers of precise copies of the same pattern.

The melting points of some of the more important metals are as follows:

TEMPERATURE OF FUSION OF COMMERCIAL METALS.

	FAHR.	CENT.
Mercury	−39°	−39°
Tin	420	216
Bismuth	490	254
Lead	630	332
Zinc	700	371
Silver	1,280	693
Brass	1,870	1,021
Copper	2,550	1,118
Cast Iron	2,750	1,510
Wrought Iron	4,000 (?)	2,201 (?)

The temperatures of fusion of pure iron, or of wrought iron, are very high, and are not precisely known, no means of accurate measurement having yet been applied to their determination.

The following very complete table will serve for reference in more extended work.*

MELTING POINTS OF PURE METALS.

FUSIBLE ABOVE RED HEAT.			FUSIBLE BELOW RED HEAT.		
	F.	C.		F.	C.
Silver	+ 1873°	+ 1023°	Mercury	−39°	−39°.8
Copper	1996	1091	Rubidium	+101.3	+38.5
Gold	2016	1102	Potassium	144.5	62.5
Cast Iron	2786	1530	Sodium	207.7	97.6
Pure Iron,			Lithium	356	180
Nickel,	? Highest heat of the forge.		Tin	442	227.8
Cobalt,			Cadmium	412.5	228
Manganese,			Bismuth	497	259
Palladium,			Thallium	561	294
Molybdenum,			Lead	617	325
Uranium,	Do not melt in the forge.		Tellurium	615 (?)	324
Tungsten,			Arsenic	?	?
Chromium,			Zinc	773	412
Titanium,			Antimony	red heat.	
Cerium,					
Osmium,	Fusible only in Oxyhydrogen flame.				
Iridium,					
Rhodium,					
Platinum,					
Tantalum,					

Latent Heat.—In passing from the solid to the liquid state, a certain amount of heat disappears, being expended in producing this change of physical conditions.

Latent Heat, as this is called, varies in amount with dif-

* For approximate values of temperatures of fusion of alloys, see later.

ferent substances. Following are the latent heats of several, as obtained by M. Person, expressed in thermal units.*

LATENT HEATS OF METALS.

	CENT.	FAHR.
Tin	14.25	25.65
Bismuth	12.64	22.75
Lead	5.37	9.67
Water	79.25	142.65
Silver	21.07	37.93
Cadmium	13.66	24.59

Chemical Character.—Chemically, the metals exhibit the same variation of properties as physically, and the line of demarcation between the metals and the metalloids is no more definitely fixed. They are acid or basic in combination, and resemble the metalloids more or less nearly in chemical action, according to the proportion as well as the nature of the elements with which they combine. Their oxides are usually basic, but often acid. The alkaline metals unite with oxygen with great rapidity to form alkaline oxides; the common "useful" metals are oxidized readily, but less freely than the preceding, and gold, silver, platinum, and others, have little affinity for oxygen, and do not easily corrode. Nearly all metals combine freely with sulphur, and their sulphides form, in some cases, extensive deposits which are worked for the market.

Alloys are formed by fusing together two or more metals. In the alloys, metallic qualities and chemical properties are not always completely altered or masked, as is the case in chemical combinations with the non-metals.

* This thermal unit is the quantity of heat required to raise the temperature of unity in weight of water at maximum density, one degree in temperature. For values of constants, relating to the non-ferrous metals, expressed in "C. G. S." units, see Appendix, Part I.

The physical properties of the alloys are, however, sometimes quite different from those of the constituent metals, notwithstanding the fact that the compounds formed are apparently not definite, as in cases of purely chemical combinations. It would appear probable that the force of chemical affinity performs some part in the formation of the alloy. It is not improbable that a definite compound is usually formed which either dissolves, or is dissolved in, any excess of either constituent which may be present.

Examples of alloys are seen, in gold and silver coins, in which the precious metals are hardened by alloying them with copper, to give them greater durability. Copper is too soft and tough to allow of its being conveniently worked, and it is, therefore, for most purposes, alloyed with tin or zinc, and these alloys—bronze and brass—are, by varying the proportions of the metals used, adapted to a wide range of useful application. Alloys of copper and tin exhibit strikingly the fact, noted above, that the alloy may have widely different properties from either constituent.

Speculum metal is composed of 33 per cent. of tin fused with 67 per cent. of copper. Its color is nearly white, it is extremely hard, exceedingly brittle, and takes a magnificent polish. The latter property gives it value for reflectors of telescopes. Its metallic lustre resembles neither of its constituents, and its tenacity is but about 20 per cent. of that of the weaker metal.

Type metal, also, formed by alloying lead and antimony, in the proportions of four of the former and one of the latter, is a hard alloy, capable of being cast in moulds, taking form very perfectly, and it differs greatly in its properties from either lead or antimony.

It is usually found that the temperature of fusion of an alloy is below, and often considerably below, that of either constituent metal. The strength of alloys is often greater than that of the metals composing them.

CHAPTER II.

IRON AND ITS ORES.

Iron is the most important of all the metals, not only because of superiority in its combination of strength, ductility, malleability, facility of welding, of casting, and otherwise assuming useful shapes, and the wide range of character which it takes when united in various proportions with carbon and other elements, but also in consequence of the wide and abundant distribution of its ores, and of the ease with which the metal may be reduced from them by simple metallurgical processes, and the facility with which it may be given any one of its many shades of quality. As cast iron, it is obtained either readily fusible or difficult to melt, hard and brittle, soft and readily worked, or finally as strong and elastic as the cheaper grades of wrought iron. As wrought iron, it may be obtained nearly as soft and ductile as copper, or harder and stronger than any metal except steel. Its property of uniting by welding gives it an inestimable value for general construction. As steel, its great strength and elasticity, and its wide range of quality, as given by tempering, and by variation in proportion of hardening elements, fit it for uses of the utmost importance, and enable it to fill a place for which no other material is nearly as well adapted. Iron ores have a range of distribution and an abundance only comparable to that of the fuels which are essential to their reduction.

Wrought, or Malleable Iron, has been known from a period which antedates history, and by several nations. A wedge of iron has been found in the Great Pyramid; hence it was known in the time of Moses, 1500 B.C., and in the time of Cheops, 3500 B.C., or possibly in the 7th Egyptian Dynasty, or still further back, in the time of Menes, 4400 B.C.

Mr. A. L. Holley exhibited, at a meeting of the Institute of Mining Engineers, a specimen of iron, which had probably been made centuries before the Christian era, having been found under the obelisk, which is now to be seen in Central Park, New York City. Dr. Wendel found it to have the following composition:

Iron	98.738
Carbon	0.521
Sulphur	0.009
Silicon	0.017
Phosphorus	0.048
Manganese	0.116
Nickel and cobalt	0.079
Copper	0.102
Calcium	0.218
Magnesium	0.018
Aluminum	0.070
Slag	0.150
Total	100.096

Tested by tension, its strength was 54,500 pounds per square inch (3,831 kgs. per sq. cm.) and it stretched 14 per cent., which are fair figures for modern iron.

Notwithstanding the antiquity of iron, its use was generally unknown to the inhabitants of the East Indies, owing probably to the fact that "iron, though the most common, is the most difficult of all the metals to obtain in a state fit for use; and the discovery of the method of working it seems to have been posterior to the use of gold, silver, and copper."

The precious metals, being more fusible, and oftener found in a virgin state, are more readily observed by mankind, and were, therefore, earlier known.

In the earlier ages, gold and silver, and particularly copper, were employed for many purposes for which iron is now used.

The most abundant deposits of mineral treasure are usually covered by the largest growth of wood; it has been naturally suggested that in clearing the land by burning the forests, veins of metallic ore lying near the surface would be

fused by the heat, and thus discovered But iron ore, requiring a more intense heat, remained longer undiscovered. Even when brought to the metallic state, iron, in most of its forms, is not worked as easily as the more malleable, but rarer metals.

We find that the principal weapons, tools, and metallic manufactures of the early ages, and of the half-civilized nations of modern times, were formed of bronze, brass, and alloys of tin with gold, silver, and copper. Nevertheless, the statement that bronze was made before iron is doubted by Percy, the eminent English metallurgist.

When America was first discovered and settled, the use of metals by natives was principally confined to the manufacture of trinkets of gold, silver, and copper, with which to adorn the person. Their best tools and their weapons were sharpened flints and shells; and their only means of felling a tree, and of forming a canoe from its trunk, was by the application of fire. A few tribes possessed the art of casting in gold and silver, and many specimens of their art have been found in the *huacas* or graves of those races.

Weapons of copper alloyed with tin were made by the Peruvians and Mexicans. Lead was known, and knives, of iron which is supposed to have been of meteoric origin, have been found among the Esquimaux and the savages of the Northwest coast.

Tubal Cain is stated* to have been an artificer in iron as well as brass.

Homer exhibits a knowledge, not only of the existence of the metal and of the methods of working it, but also of the art of tempering what was probably a crude form of steel, and which afterward became quite abundant among both Greeks and Romans.

The following passage, translated by Cowper, occurs in the description of the games instituted by Achilles on occasion of the death of Patroclus:

> " The hero next an iron clod produced,
> Rough from the forge, and wont to task the might

* Genesis, iv. 22.

> Of King Aetion; but when him he slew,
> Pelides glorious chief with other spoils
> From Thebes conveyed it in his fleet to Troy.
> He stood erect, and to the Greeks he cried:—
> 'Come forth, who also shall this prize dispute.
> How far so e'er remote the winner's fields,
> This lump shall serve his wants five circling years;
> His shepherd shall not, or his plower need
> In quest of iron seek the distant town,
> But hence he shall himself their wants supply.'"
>
> *Iliad*, b. xxiii.

Æschylus, who lived four hundred years before the Christian era, writes of iron and steel as being worked by the Scythians or Chalybians, and the name Chalybs thus came to be applied by the Greeks to their best qualities of steel; and through the Latin has acquired a position in our own language, water and chemical compounds containing iron being known as "*chalybeate*."

The "northern iron" mentioned by Jeremiah, and the "bright iron" of Ezekiel, in which the Tyrians traded, were perhaps the product of Chalybia—"the mother of iron," as Scythia was called by a Greek poet.

It is thought that Chalybia supplied the early Britons with iron, and they were taught the art of smelting by the Phœnicians. Chariots armed with scythes, spears, broadswords, and iron rings, and also iron money, seem to have existed in Great Britain before the Roman Conquest, but improvements in smelting and working iron were introduced by the followers of Julius Cæsar.

The Romans, in the time of Diodorus Siculus, had already learned of the existence of the still noted ores of Elba.

Pliny, the Elder, speaks of the multitudinous uses of the metal, and quotes Hesiod to the effect that the Dactyli brought iron from Phrygia into Greece nearly fifteen centuries before Christ.

The Egyptians, before the time of the Ptolemies, probably had a knowledge of the metal and of the methods of working it; and the Assyrian antiquities contributed to modern museums frequently contain forged iron, and are

attributed to a period preceding, by nearly a thousand years, the birth of Christ.

Implements, not only of copper (which is said to have been so tempered by a process, no longer known, as to be elastic and hard enough to cut granite with ease), but also iron, have been left to us by the ancient Egyptians..

The existence of the pillar of iron at Delhi, in India (See sketches in figures 1 and 2), indicates that iron working had, at the time of its erection, attained a very considerable degree of advancement. The dimensions of this remarkable column are as follows:

Height above ground, 22 feet (6.7 metres).
As excavated below ground thus far, 26 feet (7.9 metres).
Estimated length not less than 60 feet (18.3 metres).
Lower diameter, 16.4 inches (41.6 cm.).
Upper diameter, 12.5 inches (31.8 cm.).

FIG. 2.—CAPITAL OF THE "LAHT" OF DELHI.

It contains about 80 cubic feet (2.2 cu. m.) of metal and weighs upwards of 17 tons (or tonnes).

The date of this column (which seems to be made up of a large number of blooms of 60 or 80 pounds (27 to 36 kilogrammes) weight, each welded together at the forge), is not well ascertained, but is supposed to be not far from 900 B. C. Dr. Percy has analyzed and tested a piece of this iron column, of which a cast has been placed in the South Kensington Museum, London, and has pronounced it to be soft wrought iron.

Col. Pearse discovered archaic iron and steel tools in tumuli in India, which are supposed to date from 1500 B.C. Iron beams have been found in Indian temples, and the early Chinese and Egyptian peoples attained some degree of success in iron making on a small scale.

Early Methods.—The methods by which these early iron-working nations reduced iron from its ores and gave it its various characteristic forms are not well determined.

It is quite certain that both wrought iron and steel were known before cast iron, which seems to be a comparatively modern product.

At the time of the discovery of Great Britain by the Romans, the inhabitants had already learned to reduce iron ores in the rude furnaces which are still in use in a modified form in many parts of the world, and known as "*bloomaris*"— a simple open furnace with a blast produced sometimes artificially, and sometimes merely by leading a draught passage out from under the hearth toward the side from which came the prevailing strong winds.

A *fabrica*, or military forge, was erected at Bath, near the well-wooded, iron producing, hills of Monmouthshire and Gloucestershire, about A. D. 120. There are great beds of iron cinders in the forest of Dean, in the vicinity of Sheffield, and in other parts of England, and in which Roman coins have been found imbedded, which prove the manufacture of iron by the Romans to have attained a very considerable magnitude. The earliest of these masses of scoriæ were found on the hill-tops, where the furnaces had been erected to obtain more powerful currents of air. These currents were admitted through holes on all sides. After the invention of the bellows, the furnaces were built in the valleys. The slag of these ancient bloomaries was rich in iron, and they, for a long time, furnished to more modern furnaces a supply of material from which was made very excellent iron.

The increase of the iron manufacture necessarily caused the destruction of the forests, and this became so serious that an attempt was made, in the first year of the reign of Queen Elizabeth, to prevent it. The destruction of trees was not only prohibited, but also the erection of iron works within certain limits. Similar structures have been found in Belgium, which are attributed to the Romans of Cæsar's time, and Mungo Park found others in modern times in Africa. In these furnaces but a moderate heat could be obtained, but small quantities of ore could be worked at once, and the deoxidation of the ore must have been very imperfect, and the work must have been exceedingly slow. As the tem-

perature attainable was insufficient to fuse the ore, and as the methods of hammering the reduced metal must have been very imperfect, the product was a crude and imperfectly worked wrought iron.

The same method of extracting iron from its ores in a malleable state, as in ancient times, is now practiced by the natives of India, Borneo, and Africa. This ancient method is also still employed in Europe, and in some portions of the United States. It is called the Direct Process, to distinguish it from the modern or Indirect Process, in which cast iron is first produced.

The Direct Process.—It is not known when this method originated. The apparatus used is very simple, consisting of a small furnace or hearth and a blowing machine. Very rich ores are used, and charcoal is the only fuel. A small mass of iron is obtained, which is malleable, and is hammered out into a flat, square mass, called a bloom. This is then drawn out under the hammer into a bar. The term bloom is still retained in common use, and is clearly derived, according to Dr. Percy, from the Saxon word *bloma*, which is defined by Bosworth as "metal, mass, lump." The furnaces in which this process was carried on, were called, as they are still, Bloomaries.

It is apparent from the large accumulations of slag which are found in various parts of India, that the Hindoos have carried on the Direct Process from a very early time, and very little progress seems to have been since made in the art. These furnaces are very small, and hours of unintermitted labor were required to reduce a bloom weighing a few pounds only. The ores used are usually magnetic oxide and rich red and brown hematites.

The bloomary furnaces are divided into three types. The first kind is that employed in the western part of India, and through the Deccan. This is the rudest furnace in use. The other kinds are found in Central India, and in the Northwest. They are quite similar to the simple Catalan forges and to the German Stückofen. They are far superior to the first kind.

The Catalan Forge consists of a furnace, blowing apparatus, and a hammer. A fall of water of from 11 to 12 feet (3.3 to 3.6 metres) is usually secured to drive the blowing machine. Brown hematite ore is usually preferred, but other ores are used. Charcoal is always used for fuel.

The Direct Process of iron making was practiced in the French Pyrenees as early as A. D. 1293, and has never since been completely given up. Dr. Percy considers it probable that it was established in Spain and France much earlier than the date just given. Originally, it was conducted on but a very small scale.

These rude furnaces, gradually, by increase in size and the application of a more powerful blast, probably grew into the now familiar form of the blast furnace; and the character of the product became as gradually changed, until it assumed the form now known as cast iron.

At what period this revolution in iron manufacture was completed, is not definitely known. It is probable that cast iron was regularly made as early as the middle of the sixteenth century.

During the early part of the seventeenth century, many attempts were made to smelt iron with pit-coal, which had already come into somewhat extensive use for domestic and other purposes.

In 1619, Dud Dudley, a son of Lord Edward Dudley, while superintending his father's furnaces in Worcestershire, England, succeeded in using coal from the neighboring mines as a substitute for charcoal, and made *three* tons per week of cast iron. A patent was issued to Lord Dudley during the same year, and its date marks the beginning of a brief period of successful manufacturing.

In 1651 commercial difficulties drove Dudley out of business, and the use of pit-coal ceased for nearly a century.

About 1735, Abraham Darby, then the manager of the Colebrook Dale Iron Works, made the experiment of treating coal as he had been accustomed to treat wood in preparing charcoal for the blast furnace. After a trial of the coke thus made as a substitute for charcoal (the experiment occupying

several days), his success was complete, and from that time to the present, the use of coal and coke has continued without interruption.

It was but a short time before this that the art of making castings had been acquired or rediscovered by Abraham Darby, the father of the Darby just mentioned. This was in 1706.

Glasgow and its vicinity has now become a very important iron district; this development has been very rapid, particularly since the invention of the hot-blast.

The hot-blast process has produced a complete revolution in the trade of all iron-producing countries, and this change introduced the latest era in the history of this metal—the era which precedes the age of steel.

For this process a patent was secured by Mr. Neilson, in 1824. The patent covered an improved application of air to produce heat in forges and furnaces where bellows or other blowing apparatus are required. The blast was to be heated in a closed air-vessel to a high temperature, before being carried to the furnace, the air vessel being heated by a fire separate from that to which the blast was applied. Such facilities have been thus afforded for the reduction of refractory ores that the quantity of iron produced per ton of coal has been increased very greatly, and the coal does not necessarily require to be coked, or the ores to be calcined.

The more important of the recent changes of the iron manufacture have been: the direct production of wrought iron from rich ores in a reverberatory furnace, accomplished by Mr. Clay, in 1840, and later, by Siemens; the use of oxide of manganese in the production of steel, first attempted by Reynolds, in 1799, and now universally practiced.

Crane, in 1836, and Budd, in 1842, introduced the use of anthracite, stone-coal, or culm in blast furnaces, with a blast of high pressure heated to a high temperature. The application of peat has also been occasionally successful, very good qualities of iron being produced with it in the United States, on the Continent of Europe, and in Ireland.

Puddling.—In 1783–84, Cort, of Gosport, invented the processes of puddling and rolling, which he foresaw were to become of great importance in the production of iron. He obtained his first patent in 1783, for "a peculiar method and process of preparing, welding, and working various sorts of iron, and of reducing the same into '*uses*' by machinery, and a furnace and other apparatus adapted to the same purpose." His second patent was issued in February, 1784, upon his process of "shingling, welding, and manufacturing iron and steel into bars, plates, rods, and otherwise, of purer quality, in larger quantities, by a more effectual application of fires and machinery, and with a greater yield, than any method before put in practice."

In his first patent he described his system of faggoting and heating scraps and bars, welding them into a mass, and compressing them into form by means of rolls and the hammers. We are, therefore, indebted to Cort for the introduction of the rolling mill.

In his second patent Cort claimed a reverberatory furnace having a concave bottom, into which the fluid metal is run from the smelting furnace. This furnace was heated by coal. He showed how the cast metal could be rendered malleable by a process of stirring with rabbles, or puddling, while exposed to the oxidizing current of flame and air. He describes the stirring of the metal till ebullition ceases, and its collection, as it becomes viscous and pasty, into balls for blooms. He describes the hammering of these to get rid of the slag, and their subsequent reduction to a marketable shape by the processes described in his first patent.

The extensive introduction of the steam engine of James Watt marked the commencement of a new epoch in the history of iron manufacture. It soon came into general use, its immense power, economy, and convenience of application, making it of inestimable value.

Puddling and refining iron by the action of gas flame have been practiced in Silesia a long time, and more recently Mr. C. W. Siemens has applied his regenerative gas furnace to this work. Nasmyth invented the steam hammer in 1842.

It has received many modifications in the hands of Morrison, Sellers, Condie, and others.

The utilization of the waste gaseous products of the puddling furnace was attempted by Teague, in 1832, and Meckenheim, in 1842, and by many later inventors.

Kelly, in the United States, and Bessemer, in Great Britain, have introduced the pneumatic process of making wrought iron and steel by decarbonizing it in a fluid state by forcing through it a multitude of streams of air. Other manufacturers, by modifying the puddling process, are producing a homogeneous and malleable steel in the form of plates and bars.

The Six Epochs.—Fairbairn specifies five distinct epochs in the history of the iron trade.

The *first* that of the employment of an artificial blast to accelerate combustion.

The *second* that of the employment of coke for reduction, about the year 1750.

The *third* that of the introduction of the steam-engine.

The *fourth* epoch is that of the introduction of puddling and rolling iron.

The *fifth* is that which is marked by the application of the hot-blast, which has increased the production of iron four-fold, and has enabled the iron master to smelt otherwise useless and unreducible ores.

A *sixth* should be added—that of the introduction of the pneumatic and open-hearth processes of making ingot irons and steels.

American Iron Making.—At the date of the colonization of America the demand for iron was greatly increased, while the production of British furnaces, already insufficient for the demand, was declining with the destruction of forests.

The enormous extent of the American forests, and the supposed mineral wealth of America, attracted many adventurers. In their explorations rich deposits of iron ores were discovered, and early attempts were made to work them.

The commencement of the iron manufactures in the British Colonies dates back to the beginning of the seventeenth

century. In 1610 Sir Thomas Gates testified before the Council in London that in Virginia were "divers sorts of minerals, especially of iron ore, lying upon the surface of the ground, which had been tested in England and found to make as good iron as any in Europe."*

In 1619 the London Company sent out a large body of emigrants. Of these, about 150 had been engaged in the manufacture of iron, and it was proposed to erect iron works in the colony. Works for smelting the ore were soon built.

The Ores of Iron are almost exclusively oxides and carbonates of varying degrees of purity. Ores cannot properly be so called when containing less than 25 per cent. of iron. For special purposes, the compounds of iron with sulphur and other elements are sometimes, though infrequently, utilized.

Ores of iron are distributed in great variety throughout every quarter of the world and in the deposits of nearly every geological age, but principally, and in the greatest purity, among the older rocks. The Huronian and Laurentian systems of North American rocks, the metamorphic rocks of Sweden and Norway, the Devonian deposits in England and the north of Europe, the rocks of Spain, Sardinia, and northern Africa, and the carboniferous limestones of the northwest of England, are all yielding ores of great richness and purity. The carboniferous deposits offer, in many localities, excellent ores heavily charged with combustible material.

The Oolitic ores are often worked, but usually contain a serious amount of phosphorus.

The United States are very rich in iron ores, and deposits are found in nearly every State.

The State of Michigan, on the borders of Lake Superior, contains immense deposits of very rich and pure ores; quite as valuable ores are found near Lake Champlain, in New York; and the State of Missouri is equally fortunate in the possession of deposits near St. Louis, which are not excelled by any known ores. New England, New York, New Jersey, Pennsylvania, and the whole range of the Alleghanies, in fact, extending to the Gulf of Mexico, contain large, accessible,

* *A True Declaration of Virginia*, p. 22.

and valuable beds. The States of Ohio, Illinois, and Indiana are underlaid, in many places, by iron ore, and every year brings to light new deposits and sees new workings established.

The Atlantic coast of the United States is the water-shed of the Alleghanian range of mountains, and consists of primary rocks. The Mississippi valley and the interior of the country generally is underlaid by the secondary formations, while the tertiary rocks border the former.

The Ores of Iron are classified by the geologist as:

(1.) Primary—Magnetic, Specular, and Red Hematite.
(2.) Brown Hematites.
(3.) Fossil Ores—from the Upper Silurian.
(4.) Carbonates—usually from Coal measures.
(5.) Bog Ores—of recent origin.

The mineralogist classes the ores as follows:

MINERALOGICAL CLASSIFICATION OF ORES.

ORES.	CRYSTALLINE FORM.	COLOR OF POWDER.	HARDNESS.	SPECIFIC GRAVITY.
	Ferric Oxide—Red Hematite.			
Hematite.....	Hexagonal.....	Cherry red to reddish brown.....	5.5-6.5	5.5-5.3
	Ferric Oxide Hydrated—Brown Hematite.			
Limonite.. ...	Massive.....	Yellowish brown to rusty yellow....	5-5.5	3.6-4
Xanthosiderite.	Massive or fibrous.	Ochre yellow.....	2.5	
Limonite.....	Massive or earthy.	Yellowish brown ..	5-5.5	3.6-4
Göthite.....	Orthorhombic ..	Brownish to ochre yellow.....	5-5.5	4-4.4
Turgite.....	Massive.....	Reddish.....	5-6	3.5-3.7
	Ferrous Carbonate—Spathic Ore.			
Siderite.....	Hexagonal.....	White.....	3.5-4.5	3.7-3.9
	Magnetic Oxide—Magnetite.			
Magnetite. ...	Isometric.....	Black.....	5.5-6.5	4.9-5.2

The chemical structure is as follows:

ORES.	FORMULA.	PER CENT. METALLIC IRON.	WATER.	CARBONIC ACID.
Hematite	Fe_2O_3	70.00		
Limonite	Fe_2O_3, $3H_2O$	52.34	25.23	
Xanthosiderite	Fe_2O_3, $2H_2O$	57.14	18.37	
Limonite	$2Fe_2O_3$, $3H_2O$	59.90	14.43	
Göthite	Fe_2O_3, H_2O	63.03	10.11	
Turgite	$2Fe_2O_3$, H_2O	66.28	5.33	
Siderite	FeO, H_2O	48.27	.....	37.93
Magnetite	Fe_3O_4	72.41		

There are also two species of native iron—iron found naturally in metallic form. These are meteoric and telluric iron; the former is found occasionally in all parts of the earth's surface, and the masses discovered vary in size from several tons weight to that of fine grains, and even powder; the second is found in but two or three places on the earth's surface, imbedded in rocky strata.

The characteristics of these several forms of minerals are widely different mechanically, physically, and chemically.

Meteoric Iron resembles closely, in all its characteristics, the artificially produced metal which will be minutely described in the proper place. It often forms a part of earthy meteorites, but is usually found isolated or only alloyed with nickel and with a trace of other elements. The largest masses have been found in Siberia, Mexico, and South America.

A meteoric iron from California, analyzed by Cairns, gave the following:

Iron	81.480	Calcium	0.163
Nickel	17.173	Carbon	0.071
Cobalt	0.604	Silicon	0.032
Aluminum	0.088	Phosphorus	0.308
Chromium	0.020	Sulphur	0.012
Magnesium	0.010	Potassium	0.026
Total			99.987

CHAPTER III.

THE REDUCTION OF IRON ORES—PRODUCTION OF CAST IRON.

Preliminary Operations.—The ore supplied to the furnace manager, to whom the duty of superintending all the operations of reduction of the metal is intrusted, is usually subjected to some preliminary treatment before the process of reduction or "smelting" is attempted at the smelting or blast furnace.

These preparatory processes are:

(*a*) "Grading" the ore.

(*b*) Calcination or roasting.

(*c*) Mixing to make up the desired proportions of ore-charge.

The Grading of the Ore is not necessary at the furnace when it has already been properly done at the mine. When received at the furnace it is stored in "bins," each of which receptacles is appropriated to one grade of ore. Several grades are frequently kept in the stock-house, both because it is generally found that mixtures work best in the furnace, and because the varying demands of the market can be met by changing the proportions of the several ores in the charge to produce higher or lower grades of metal.

When the sorting at the mines has not been carefully done, or when a greater number of grades than usual are required, sorting is also practiced at the furnace, and the ore is then distributed to the several bins of the stock-house, which building is erected as near the furnace-stack as possible.

Calcination and Roasting are sometimes conducted at the mines, but more usually at the furnace. The terms calcination and roasting are often used interchangeably by

iron makers. Some authorities make an important distinction.

Wagner defines calcination as the exposure of ores to a moderately high temperature with or without access of air, and roasting as the heating of ores to a higher temperature, but under the fusing point, with access of air.

The object of calcination is to expel all volatile constituents, as water, carbonic acid, or bituminous substances, and to soften and open the ores, making them more permeable to the reducing gases, and more easily reducible to the metallic state.

Roasting produces the same result, but more promptly and completely, and the access of air secures oxidation of combustible constituents, and the change of protoxides to peroxides, as occurs in the roasting of spathic iron ores and of magnetites.

The addition of salt is practiced in the roasting of some ores, as of silver, to produce volatilization by conversion into chlorides.

Sulphur, arsenic, zinc, and some other elements, pass off as acid or basic oxides, either free or united with other compounds forming salts.

Iron ores are usually subjected to the second or roasting process. Magnetite ore is roasted to secure openness of structure and to drive off the sulphur and arsenic, and to oxidize the blende, galena, and other impurities which often accompany it; specular iron ores are roasted to drive out pyrites, and other ores to remove water and carbonic acid. Ores containing silex must be roasted. Especial care is needed when gray iron is to be made.

Roasting is performed either in heaps in the open air, or in kilns. During the process the ores lose from 2 to 5 per cent., where nearly pure oxide, to 20 or 30 per cent. in the case of argillaceous ores, and 40 or 50 per cent., in some cases where a blackband, highly charged with carbonaceous matters, is roasted. In the latter case the combustible material in the ore is often nearly sufficient to supply the heat required in the process. This treatment of ores is less frequently

adopted in the United States than in Europe, and has been less usual since the introduction of the hot blast than previously. It is still invariably adopted with ores containing large quantities of volatile substances, and, in Sweden, is usually practiced even with ores, like the magnetites, which contain little or no such matter.

Argillaceous ores, originally containing 30 per cent. metallic iron, contain, after roasting, about 55 per cent.; similarly the percentage of metal rises, in the blackband ores of Scotland, from 33⅓ to 70 per cent. By thus increasing the richness of the ore a considerable economy of expenditure of fuel in the blast furnace is obtained, and as roasting may often be carried on with fuel unfit for use in the furnace, a marked saving is often effected. In the roasting of blackband ore some deoxidation may occur, but more usually the result is a peroxidation of any protoxide present.

Roasting in Heaps is practiced where fuel is cheap and ore inexpensive. It requires a considerable amount of fuel, necessitates keeping large quantities of ore and fuel on hand, and the ore-heaps occupy a large area of ground. The process is uncertain and irregular in its operation, as it is impossible to secure perfect uniformity in the distribution of heat.

The ore to be roasted is first broken into lumps of from 4 to 8 inches (10 to 20 centimetres) diameter. A bed of fuel is prepared, either coal or wood, of a thickness of from 6 to 10 inches (15 to 25 centimetres); over this is spread a layer of ore of from 1 to 2 feet (0.3 to 0.6 metres) in thickness, according to the kind of ore and size of lumps. The coarser and more refractory ores are piled higher. The ore and fuel are thus arranged in alternate strata, and the pile is raised to a height of from 5 or 6 to 30 feet (1.83 to 9.1 metres). Where charcoal is used as fuel the base of the pile is generally of wood, in billets, and the volume of fuel is from 5 to 20 per cent. that of the ore; the former proportion is usual under favorable conditions. Where the ore is fine, chimneys are formed in the heaps, in which the fires are started, and by which the heat is distributed and the combustion regulated. The requi-

sites of satisfactory working are slow combustion, uniform distribution of materials, and a temperature moderately high but always below the fusing point of the ore.

The proportion of fuel to ore is necessarily determined by experiment. The time required varies with the size of the heap, and sometimes extends over several months.

Roasting in mounds instead of in widely spread low heaps, is sometimes practiced. It requires less fuel, but costs more for labor, than the preceding method. A space of about 100 square feet (9.3 square metres), usually oblong in shape, is surrounded by low walls with fire chambers within or below them. Small chimneys are built for draught. In some cases several of these structures are built under a shed roof, divided from each other by party walls. This method is best suited for use with finely crushed materials, and demands much care and some skill on the part of the attendants.

Roasting in Kilns, or in shaft furnaces, is practiced very generally, as it is much more economical of fuel, more uniform in results, and far more convenient than the methods already described. It is, therefore, far preferable, as is often the case in the United States, where fuel and labor are not so cheap as to make the saving insufficient to compensate for increased cost of plant.

The kilns should have large capacity in order that the roasting may be done slowly and effectively. They should work continuously and regularly. The ore and fuel are introduced in alternate layers at the top of the furnace, and the roasted ore is removed at the bottom. Several kilns are worked, usually at each smelting furnace. The best kilns are built of boiler plate and lined with fire-brick. The ore and fuel are often brought in cars to the kiln, the rails being laid over their tops, and the stock dropped directly into the top of the kiln.

Preliminary roasting is sometimes omitted, and the blast furnace is given exceptional height in order that roasting may be completed in the furnace itself before the process of reduction commences. The limit to height of furnace, which is fixed by the strength of the fuel and ore, or by the maximum

"burden" practicable, also places a limit upon the extent to which this method can be carried.

The time required for expulsion of volatile matters and for producing the desired change of structural character, varies with every ore. It is usually said that magnetites and sparry ores should be held at high temperature a week, and the less refractory ores from 2 to 4 days, in the kiln. In heaps, more time is needed, as a week to each 20 tons (20,320 kilogrammes), where the quantities vary from 50 to 150 tons (50,800 to 152,400 kilogrammes). The immense piles fired in Europe sometimes burn several months, and the weathering of ores, which is a slow process of roasting by the heat of the sun and of oxidation, sometimes occupies years.

Making up the Furnace-Charge is an operation which demands both a knowledge of the chemistry of the blast furnace and of ores, and actual experience in furnace management; the last is absolutely essential to satisfactory production.

The proportions of the charge are determined by the character of the ore, the fuel, and the flux, by the size and method of working of the furnace, and by the character of product required. In general the object to be attained is to secure reduction of the ore most rapidly and completely, with the least expense possible, without risk of injury to the furnace, without the introduction of injurious elements into the pig metal, and to produce a metal of the highest degree of carbonization consistent with other prescribed conditions.

The Character of the Ore is not always a matter of choice. When possible, magnetic ores are selected where the cast iron produced is to be made into fine cast steel. Specular or magnetic ores are suitable for "low" steels and fine wrought iron, and the other ores make foundry iron of various qualities.

Charcoal, as fuel, contaminates the product least. Coke and anthracite coal, if carefully selected, make good iron; the bituminous coals are least valuable, and are generally used only for making cheaper grades, as they contain objectionable proportions of sulphur.

The Constituents of the Charge are weighed out separately, and, for small furnaces especially, are very carefully mixed before charging into the furnace. In mixing, each kind of ore and the flux, after it has been broken properly, is weighed, and spread over the floor in strata of uniform thickness, one over another, and the charges are taken in barrows to the furnace from this heap.

Large furnaces are charged with a stated number of barrows of each material regularly in rotation.

Changes of proportions are sometimes necessary. A reduction of the proportion of fuel produces a greater tendency to yield white iron, and gray iron is obtained by using some excess of fuel. When furnaces work cold, and when "bears" commence forming, the proportion of fuel must be increased. Such changes should always be made as gradually as possible in order that their effect may be observed in time to avoid injury to the furnace, waste of fuel, or loss of quality of product.

The Form and Dimensions of the Blast Furnace in which the ore is commonly reduced vary greatly. Charcoal furnaces, shown in the figure, are usually of small size; furnaces using coke or anthracite coal are often very large. The former are seldom 10 feet (3 metres) in diameter, or 40 feet (12.19 metres) high; the latter are often 75 feet (22.5 metres) high and above 25 feet (7.5 metres) in diameter of bosh, and have been built for coke in Yorkshire, Great Britain, 28 feet (8.4 metres) diameter, and a maximum height of over 100 feet (30.5 metres) has been attained.

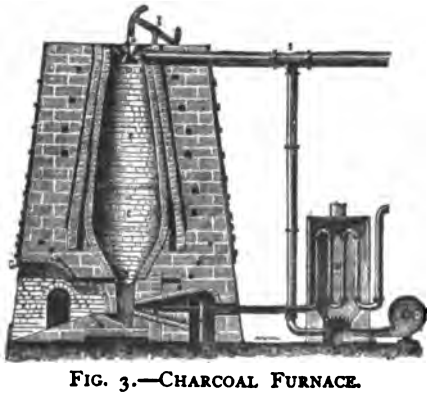


FIG. 3.—CHARCOAL FURNACE.

A charcoal furnace 9 feet (2.7 metres) in diameter and 32 feet (9.6 metres) high, making 1,500 tons (1,524,000 kilo-

grammes) of cold-blast iron per year, represents a usual practice in the United States, and a coke or anthracite furnace 20 feet (6 metres) in diameter of bosh and 65 feet (18 metres) high, with a capacity for making 20,000 tons (20,320,000 kilogrammes) of hot-blast iron per annum, is representative of ordinary practice; more than four times this product has been made. Furnaces of considerably larger size have been built.

The figure represents the warm-blast charcoal furnace. The charge is thrown from the charging-floor, *a*, into the hopper, *b*, and rests upon the cone, *D*. A lighted taper is thrown upon it to inflame the furnace gases which rise when the charge enters, and the cone is then quickly depressed and as quickly elevated again, the ore falling into the furnace during the instant that the top is thus opened.

As the fuel is burned, and the reduced ore and cinder tapped off at the bottom, the furnace is kept filled from the top.

Each charge, entering at the throat of the furnace, *D*, gradually slides down the stack, *EE*, to the bosh, *CC*, and, finally, the carbon having been withdrawn by oxidation and by combination with the iron, the latter and the slag fall into the hearth, *A*, and are tapped off at the front of the furnace.

The air which supports combustion is forced into the furnace under a pressure of from 1 pound in some coke furnaces and 2½ pounds per square inch (0.16 atmosphere) in small charcoal furnaces, to 9 pounds (0.6 atmosphere) or more in large anthracite furnaces, and at a temperature which varies from that of the atmosphere to 1,000° Fahr. (593° Cent.), and sometimes to 1,200° (649° Cent.), or even 1,400 Fahr. (760° Cent.). It enters through the tuyeres, *P*, which latter are set in the tuyere arches, *II*.

The tuyeres and the arches are kept cool by the circulation of water through them, either in coiled pipes or in their hollow walls.

The walls of the furnace are double and are separated by a space, *JJ*, which is filled with water-worn sand, ordinary soil, broken bricks, or refuse material of any kind that will not coke at the high temperature likely to exist there. The

outer walls, *KK*, are usually built of red brick, and where unprotected by an external jacket, they should be sufficiently "hard burned" to resist the action of the weather. Less strength and greater range of elasticity may be found suitable where a sheet-iron jacket covers the whole structure. The inner walls, *LL*, are constructed of fire-brick, which may be obtained of any required shape and of any convenient size from the makers. It should not be liable to great change of dimensions with change of temperature. The whole furnace is usually banded with iron hoops, or is encased in a jacket of boiler plate, which gives it strength and protects it from the injurious action of the rain.

The hearth, *nm*, is built of fire-brick arranged as in the "plate-band" of the architect, or of some refractory stone set in as large masses as possible. It is very carefully laid, and every precaution is taken to prevent injury by the escape of fluid iron through it. The hearth is sometimes floated up by the formation of a pool of molten iron below it or between its layers. It has sometimes happened, also, that the molten iron has found its way down through the foundation, and large quantities have been lost.

The reduced metal and slag fall into the crucible, *A*, and the cinder flows off through the opening between the trough, *N*, and the dam-plate, *R*, while the former is tapped out at the tap-hole, which is situated at the bottom of the crucible. The tap-hole is plugged with sand, which material is easily driven into the opening, forms a perfect seal and is readily removed by an iron bar. The front of the furnace at the dam-plate is frequently closed by a "cinder-block," through which a hole is made of proper size, and the slag or cinder issues from this continuously. Where this plan has been properly carried out, it is said to result in greater regularity of action, an increased and more uniform yield, greater economy of fuel, and a reduced waste of blast. Fig. 10, page 75, represents the modern iron-jacketed furnace, with fire-brick stoves, and all the usual arrangements of a large anthracite furnace.

The Rachette blast furnace is an European form of furnace of limited actual application. It is of rectangular hori-

zontal section, narrow and long, and widens all the way from the tuyeres to the top.

A blast furnace should be built with care and skill of the best material, and the masonry should be laid up slowly and given ample time to set. The foundation is sometimes made of concrete or beton, and, in such cases, should be given ample

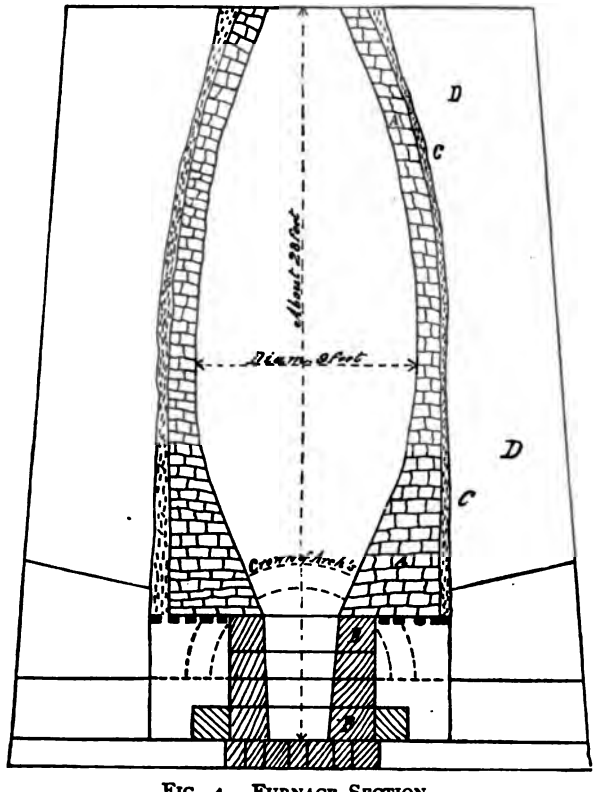


FIG. 4.—FURNACE SECTION.

depth—six to eight feet for large furnaces—and the walls of the furnace should only be started after the foundation is sufficiently firm to bear the superincumbent weight without cracking or settling. Fig. 4 is a section of a charcoal furnace of fair size, which has done good work.

Fig. 5 represents a section of one of the latest forms of

charcoal furnace now used at Salisbury, Conn. The air for this is conducted from the blower to the pipe, *A*, which is located in an oven, *OO*, into which the hot gases from the furnace are admitted through an archway, *F*. The pipe, *A*, is connected by a series of ∩-shaped cast-iron pipes or syphons, the form of the section of which is that of a compressed letter O. These syphons connect *A* with *B*, which, in turn, is connected in a similar way with *C*. The air is exposed to a very large surface, and after being warmed is carried down alongside the furnace by two pipes, one of which, *DD*, is shown in dotted lines. These pipes are connected at the lower ends with a horizontal pipe, *F*, which encircles the side of the furnace, and the air is carried down to the tuyeres, *TT*, by the branch pipes *GG*.

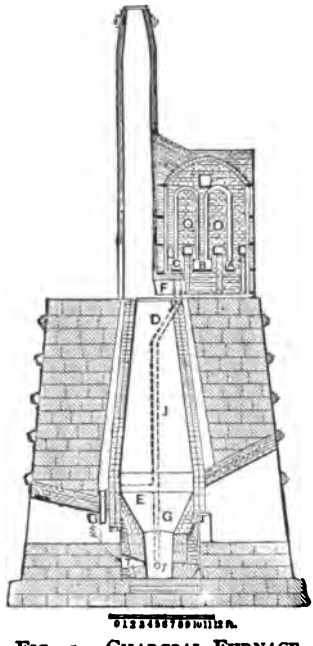


FIG. 5.—CHARCOAL FURNACE.

The blast for the furnaces is warmed up to about 400° Fahr. (205° Cent.), and has a pressure of from one-half to three-quarters of a pound per square inch (.03 to .05 atmosphere).

The Shape of the Blast Furnace is, to a limited extent, optional; narrow tops cause greatest separation of the fine from the coarse material of the charge descending in the furnace, and do not exhibit the effect of scaffolding promptly. Wide tops carry more stock, are sensitive, as indicators of scaffolding, and do not cause the separation of coarse from fine parts of charge; they usually do better and cheaper work than the preceding, provided they are driven harder than narrow furnaces. Blast pressures of nine and ten pounds (0.6 to 0.7 atmosphere) are not considered too high for anthracite or coke furnaces. A height of 75 to 80 feet (22.5 to 24.0 metres) for anthracite and coke furnaces gives a good

working condition. Scaffolding occurs whenever any part of the furnace-wall within the zone of fusion becomes cooled below the temperature of fusion.

The stock then adheres to the furnace wall and prevents the material above from descending regularly, by forming an abutment to an arch, which is naturally formed above it, and thus sustaining the whole mass, until, the supports giving way suddenly, it lets down the stock; and then the process repeats itself. This is usually checked by increasing the temperature of the blast; but it may be less effectively overcome by other means.

As coke is more bulky than anthracite, a furnace running on coke will carry but about half the stock of an anthracite furnace. Coke introduced into an anthracite furnace increases the temperature and elevates the zone of fusion. Anthracite added to coke raises the pressure by its closer packing and its pasty character at high temperatures. Tuyeres are best placed high, say 5 feet (1.5 metres) or more above the hearth, and the cinder-notch 2 feet (0.6 metres) lower, to keep the cinder well under the streams of entering air.

Putting the Furnace in Blast is an operation which requires great care and considerable time; since rapid elevation of temperatures, caused by irregular expansion, would be certain to crack the lining of the furnace, and might produce serious damage.

The dam-stone is left out of place until the furnace is heated up. A small fire is first made in the crucible, and a gentle heat gradually dries the masonry of the interior, and warms up the furnace walls. This fire is kept up some days, and is then very gradually increased by adding fuel and small quantities of ore and flux, until, after several weeks, the furnace is filled to the mouth. As the supply of fuel is increased, and the furnace becomes hot enough to reduce the ore, and to melt the cinder, ore and flux are added in larger proportions, and the blast is finally turned on, and the operation of smelting is then fairly commenced. The furnace is very gradually supplied with a larger and larger proportion of ore and flux, and its "burden" is thus increased, until,

after some weeks, it is producing a maximum amount of iron. In some cases, the furnace is filled at once to the top, and, with a low charge of ore, started at once making iron.

When the furnace goes out of blast, as it must after a run which may be a few months or may be eight or ten years, the same care is taken in cooling it down. In this case, the proportion of ore in the charge is gradually reduced and that of limestone increased, until, finally, the fire burns out, and the furnace stands full of burned lime. It is then left to cool, and is not opened until it has become quite cold.

The Chemistry of the Process of ore reduction in the blast furnace has been carefully studied, and is becoming well understood. The reactions are too complicated and numerous for description here. They are given in works on metallurgy. The principal chemical changes may, however, be briefly stated.

The charges, entering at the bell, slowly descend toward the hearth; the air, forced into the furnace through the tuyeres, rises through the mass of material filling the shaft, and, meeting with fuel at a temperature much higher than that required to produce combustion, the oxygen unites with the carbon of the fuel to form carbonic oxide and carbonic acid. The carbon dioxide at once meets with other fuel, and surrenders to it one atom of oxygen, and two molecules of carbon monoxide are produced, and this gas rises through the superincumbent material, accompanied by all the nitrogen of the air.

Below the zone of incandescent carbon, the metal present is deoxidized, and to some extent carbonized. Above this zone the rising carbon monoxide meets the unchanged ore, and at a temperature which, while permitting deoxidation, does not fuse the iron. Here a portion of the gas takes up another atom of oxygen, thus becoming carbonic acid, and in that state passes out of the top of the furnace.

The issuing gas is not entirely free from carbonic oxide. Much of the carbon monoxide escapes complete oxidation, and the furnace exhibits a gradual decrease in the proportions of carbonic oxide, and increase of carbonic acid,

from the bottom to the top. In the issuing gas, in cases cited by Percy and other authorities, the proportion of carbonic oxide falls from about 35 or 40 per cent. at the tuyeres to 25 per cent. at the top, while the proportion of carbonic acid is still more variable, but usually reaches about 12 or 15 per cent. at the furnace mouth.

The proportions in a typical case were:

	Volumes.
Nitrogen	55
Carbonic oxide	25
Carbonic acid	10
Hydrogen	6
Marsh gas	3
Olefiant gas	1
	100

The total distribution of all materials in the furnace, including gases, is given by Kent for the case already quoted, in the article above on ore-mixtures, in the table page 66.

Investigations made by Akerman, Bell, Gruner, Schinz and Tunner, have yielded some valuable results.

Schinz, of Strasburg, first showed it to be essential that the analyses of the waste gases should be made a basis of all conclusions as to the character and succession of phenomena of reduction. He showed experimentally that the influence of temperature, quantity of gases, proportion of carbonic oxide present, time given, and the quality of material, were all to be carefully observed, and that each had an important influence in determining reactions. He indicated that, when the precise character of the charge is known, it is possible to calculate, by analyzing the waste gases, the quantity of carbon not burned at the tuyeres.

Bell made a series of analyses of escaping gases, and concluded that, in the cases examined—the reduction of calcined argillaceous ores, with coke as fuel—the reduction of the ore was completed at a very low temperature, and the size and form of the pieces of ore modified the position in the furnace, and the temperature, at which the change occurs. He concludes that, with sufficient time to permit complete permeation of the ore by the reducing gases, a temperature of 637°

DISTRIBUTION OF ALL THE MATERIALS OF THE CHARGE.

CHARGE.	LBS.	IRON.	CARBON.	OXYGEN.	NITROGEN.	WATER AND VOLATILE MATTER.	SULPHUR.	PHOSPHORUS.	SILICA.	LIME.	MAGNESIA.	ALUMINA.	TITANIC ACID.	MANGANOUS OXIDE.
Ore	160.9	94.75	.....	39.62	.....	3.57	1.12	.43	13.83	1.83	.37	.37	.64	.11
Coal	130.	.91 fer's ox.	118.95	.10	.....	1.95	.....	.....	3.95	1.12	.....	3.02	.....	.....
Limestone	29.64	.....	3.49	.77 / 9.29	.....	.27	.....	.....	.67 silicon.	9.12	5.79	.24	.....	.....
Air	584.56	.....	.....	134.51	450.05	.....	.....	.....	.....	.....	.....	.....	.....	.....
Moisture in air	3.62	.....	.....	.....	.....	3.62	.....	.....	.....	.....	.....	.....	.....	.....
Total	907.82	95.66	122.44	184.29	450.05	9.41	1.12	.43	18.45	12.07	6.16	6.99	.64	.11
Subtract iron	100.00	94.75	4.15	.....	.....	.....	.....	.43	.67 silicon.	.....	.....	.....	.....	.....
Subtract slag	44.66	.91 fer's ox.	.....	.....	.....	.....	.....	.....	17.78	12.07	6.16	6.99	.64	.11
Leaves gas	763.16	.....	118.29	184.29	450.05	9.41	1.12	.....	.....	.....	.....	.....	.....	.....
Composition of gas, per cent	.....	.....	15.50	24.15	58.97	1.24	.14	.....	.....	.....	.....	.....	.....	.....
Composition of slag, per cent	.....	2.04 fer's ox.	.....	.....	.....	.....	.....	.....	39.81	27.03	13.79	15.65	1.43	.25

Percentage of carbonic acid $[CO^2 = \frac{11}{12}(3O - 4C)] = 9.58$
" " " oxide $[CO = \frac{7}{3}(3C - 3O)] = 30.07$
$= C + O = 39.65$ per cent. Ratio $\frac{CO^2}{CO} = 0.3186$.

to 842° Fahr. (336° to 450° Cent.) is sufficient for insuring complete reduction. Other authorities place the figures much higher.

The Changes in the Furnace, other than those above described, are, principally, incidental reductions of compounds of silicon, sulphur, phosphorus, and other elements, the formation and fusion of slag, and the fusion of the pig iron produced.

The silicon is principally taken away as silica in the slag, with the lime, magnesia, and a small proportion of sulphur and phosphorus possibly. The remainder passes into the iron with some carbon, the greater part of the sulphur, and nearly all of the phosphorus, and with small proportions or traces of every metallic element present in the furnace charge.

The issuing cinder is a silicate of lime and magnesia, with small proportions of other elements; and the metal tapped from the furnace contains from 3 to 6 per cent. carbon, from 1 to 3 per cent. silicon, and minute quantities of other elements. Its precise constitution will be treated of at some length hereafter.

The Specific Gravities, and Specific Heats at the boiling point of water, for materials charged into the blast furnace, are as follows:

SPECIFIC HEATS AND SPECIFIC GRAVITIES.

MATERIAL.	SPECIFIC GRAVITY.	SPECIFIC HEAT.	WEIGHT.	
			PER CUBIC METRE IN KILOGRAMMES.	PER CUBIC FOOT IN POUNDS.
Anthracite coal.....	1.27 to 1.92	0.201°	1,270 to 1.920	79 to 120
Bituminous coal.....	1.23 to 1.36	0.2009	1,230 to 1,360	77 to 85
Coke.....	0.76 to 0.82	0.1571	760 to 820	47 to 50
Soft charcoals.....	0.38 to 0.40	0.2415	380 to 400	24 to 25
Hard charcoals.....	0.45 to 0.48	0.2415	450 to 480	28 to 30
Magnetic ore.....	5.3 to 6.0	0.1667	5,300 to 6,000	331 to 374
Red hematite.....	4.7 to 5.3	0.172	4,700 to 5,300	293 to 331
Brown hematite.....	3.9 to 4.0	0.154	3,900 to 4.730	243 to 250
Spathic ores, raw....	3.6 to 3.9	0.116	3,600 to 3.900	225 to 243
Spathic ores, roasted.	4.61 to 4.73	0.16	4,610 to 4,730	288 to 295
Limestone	2.25 to 2.84	0.1666	2,250 to 2.840	140 to 177
Lime	2.00 to 3.08	0.217	2,000 to 3,080	125 to 192

Knowing these quantities, it is easy to estimate temperatures and quantities of heat wherever definite conditions of operation can be stated.

The specific heats increase slowly with rise of temperature, approximately doubling with an increase of 1,652° Fahr. (800° Cent.) for coke, becoming increased four times in the same range with limestone, and increasing 50 per cent. with lime and with hard ores, and 10 per cent. with charcoal.

At 3,632° Fahr. (2,000° Cent.) charcoal has a specific heat of 0.30, coke 0.50, pig metal 0.167, and slag 0.4.

The Size of the Blast Furnace has an important influence in determining the cost of production and the yield, as shown by Bell. The ordinary sizes of furnaces using different fuels and hot and cold blast have already been given. The direction of change has been, for many years, in that of enlarged stacks.

The largest furnaces in the world are those in the Cleveland district, in the North Riding of Yorkshire, England, the largest having been 30 feet (9 metres) in diameter and the highest exceeding 100 feet (30 metres) in altitude. It is found that neither the economy nor the yield of the furnace increases to any important extent with the increase in capacity over these extreme dimensions. The largest furnace of 30 feet (10 metres) bosh, has been reduced in diameter to 27 feet (9 metres) by lining it. With the same class of furnace, 200 cubic feet (5.7 cubic metres) of capacity is demanded per ton (1,016 kilogrammes) of iron made per day in furnaces of 5,000 cubic feet (141.6 cubic metres) contents, while 300 cubic feet (8.5 cubic metres) are required per ton (1,016 kilogrammes) with furnaces of double this size, and 500 (14.16 cubic metres) in furnaces of the largest size named.

The product of iron in the larger sizes is, at best, about equal to the weight of fuel charged. Many small furnaces use fifty per cent. more fuel. The difference in this respect is not marked between the very largest furnaces of Cleveland and those of one-half their size.

In the locality named, sizes of furnaces have been reduced to about 75 feet (22.5 metres) high, and 27 feet (8.1 metres)

in diameter as maxima, and in other places to considerably smaller dimensions.

The Height of Furnace is generally limited by the power of the materials charged to resist the pressure of the superincumbent mass as they approach the lower part of the furnace; and this limitation of height also limits the diameter of the shaft, as an excess in the latter dimension introduces a difficulty in securing a proper distribution of the ascending currents of reducing gases. The proper ratio of height to maximum diameter is fixed, by usual practice, at 3 in coke furnaces and at about 4 in anthracite furnaces. After reaching a certain altitude, also, no useful gain is secured by this transfer of heat from the gases to the material in the upper part of the stack.

FIG. 6.—TEMPERATURES OF FURNACE.

Temperature of Furnace.—Bell presents the adjacent figure as illustrating the distribution of work and adjustment of temperatures in the blast furnace; the temperature falling as the rising gases flow through the successive zones of fusion of the reduced metal, of absorption of carbon, calcining of limestone, and of reduction of ore, from a white to a dull red heat, and finally issue still hot and pass off to the stove.

The gases issuing from the top of furnaces having an exceptionally high temperature of blast, are cooler than those issuing from furnaces having a colder blast. This fact also

assists in producing a limit of temperature. The fact is due to the reception of the larger proportion of heat in the former furnace, from its blast, and the less proportion from combustion. Combustion also involves less gas, and the smaller volume is more completely cooled in rising through the furnace. The minimum temperature of gases tends to remain constant at about 392° Fahr. (200° Cent.), according to Gruner, in consequence of the regulating effect of the dissociation of the carbonic oxide, which can only occur above a fixed limit. The maximum temperature of blast, with even fire-brick stoves, may be taken at about the higher figure above given.

The accompanying graphic representation, Fig. 7, is

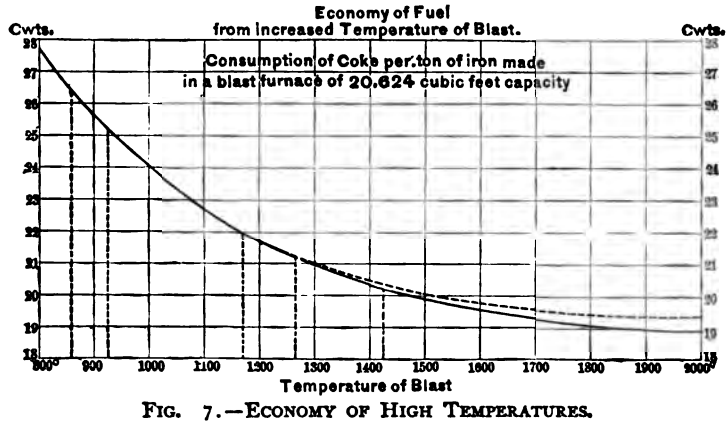


FIG. 7.—ECONOMY OF HIGH TEMPERATURES.

given by Bell, illustrating the gradual approximation to a maximum of the benefit derivable from increasing temperature of blast.

It represents the consumption of coke per ton (1,016 kilogrammes) of iron made in a furnace of 25,624 cubic feet (724.7 cubic metres) capacity. The figures corresponding to 800°, 925°, 1175°, 1275°, and 1425° Fahr. (450°, 490°, 591°, 630°, and 768° Cent.) are observed; all others are determined by plotting the curve.

The benefit of increasing the temperature of blast is least in large furnaces running on good ores.

The Iron tapped from the Furnace is led by properly

arranged channels to the "pig bed." This is usually a considerable area of sand leveled off and scored longitudinally and transversely to form moulds. The main channel, called the "sow," of each section, has on each side smaller channels of about four feet (1.22 metres) length, in each of which a "pig" is cast. The whole arrangement resembles somewhat that of a gridiron. When forge iron of high grade is to be made, the pig metal is often cast in iron moulds instead of in sand, to avoid the introduction of silicon. The pig bed is covered by a roof to protect it from the weather. This "casting-house" is built close against the stack of the furnace.

When the metal has cooled in the pig bed, the pigs are broken from the sow and are stacked in the yard, or are sent off to market after they have been graded, numbered, and distributed into lots of similar quality. The sow is sometimes also sent to market after it has been broken into pieces of proper size to handle; in other cases it is charged into the furnace and remelted.

The iron having been removed, the pig bed is made up anew ready for the next cast.

The casting-house is usually built of substantial and fireproof materials. Brick walls and an iron roof are adopted when the expense can be met without serious inconvenience.

The gases are taken from the top of the furnace through a sheet-iron pipe leading out at the side, under the charging floor, and led to the hot-blast stoves and to the steam boilers. The gas main is lined with fire-brick to prevent escape of heat and to prevent rapid oxidation of the iron pipe at the comparatively high temperature which would be given it by direct contact with the heated gases. The gas main is sometimes carried some distance a little above or below ground to the stoves.

The Hot-blast Stoves or ovens are of either iron or brick. The former consist of sets of cast-iron pipes of various forms and variously arranged in different cases, inclosed in large chambers lined with fire-brick. The blast is driven through the pipes, which are kept heated by the burning

gases from the furnace, which latter are inflamed in the inclosing chamber.

In some forms of stove the gases are burned in a "combustion chamber," and the heated products of combustion rise into an upper chamber containing the set of pipes carrying the blast. This system is claimed to possess the advantage of giving greater uniformity of heat and less danger of cracking the pipes by sudden and great changes of temperature.

In other forms, the gas is burned in contact with the pipes, and but one chamber is used.

The forms of pipe adopted are very numerous. In some ovens, mains are led across the chamber parallel with its sides. The blast enters one main and passes over into the other through a set of ∩-shaped pipes, emerging from the second main, whence it is conducted to the tuyeres. The intermediate pipes are usually of elliptical or oval section, having the longer diameter in line with the mains. This form permits expansion and contraction with change of temperature to take place with little danger of frequent fracture of the pipes.

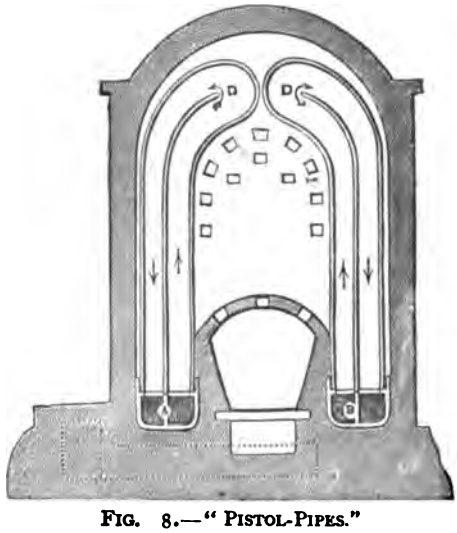


FIG. 8.—"PISTOL-PIPES."

In other forms of cast-iron pipes, they are divided by a diaphragm into two parts. The air is led into the main, rises into one of these chambers, returns through the other to the main, which it traverses until reaching the next pipe, it enters that, and thus passes from pipe to pipe until it emerges at the extremity of the main fully heated. In such stoves, several mains are laid down, each carrying a set of these double pipes.

A modification of this form of pipe which has been found

to work well is that known as the "pistol-pipe," in which the upper extremity is enlarged, giving the pipe the shape of a pistol erected muzzle downward, the well at the top of the pipe representing the butt, Fig. 8. This form permits a reduced velocity of gas at the top of the pipe, and gives an increased area of heating surface; opposite pipes have their tops turned toward each other, forming an arch above the chamber through which the hot products of combustion are rising, and the whole makes a very efficient form of stove.

A recent form of stove is fitted with iron pipes suspended from above, instead of being supported from beneath. It is stated that this modification increases the durability of iron pipes very greatly.

The least area of heating surface required to give the maximum temperature permanently sustainable by cast-iron pipes is considered by some engineers to be from 1,000 to 1,200 square feet per 1,000 cubic feet (3.26 to 3.9 square metres per cubic metre) of air passing per minute; the proportion is often much less. A pair of furnaces having three blowing engines of 84 inches (213 centimetres) diameter of blowing cylinders and 5 feet (4.57 metres) stroke of piston and making 20 to 30 double strokes per minute, when fitted up with twelve stoves, each containing 14 double pipes 16 feet (14.16 metres) long, 19 inches (48.26 centimetres) wide, and 5 inches (12.7 centimetres) deep, received the blast at a temperature of 1,130° Fahr. (610° Cent.). In this example each stove had a separate chimney.

The limit of temperature with iron stoves is so low that, at many furnaces, stoves are now built of fire-brick throughout, including heating surfaces. These are comparatively expensive, but they have been used with a blast heated to 1,382° Fahr. (750° Cent.), and even 1,742 Fahr. (950° Cent.) has been attained at times. When these stoves are constructed in such form that they are not liable to become choked with the dust carried over with the combustible gases, they are found to give excellent results. These stoves are usually constructed upon the principle of the regenerative, or the fire-brick furnace, as, for example, in the stoves of

Cowper and Whitwell. In the Sellers regenerator, the action is continuous, as in the cast-iron stoves, and the structure is, like them, composed of pipes. The material of the pipe is a refractory clay.

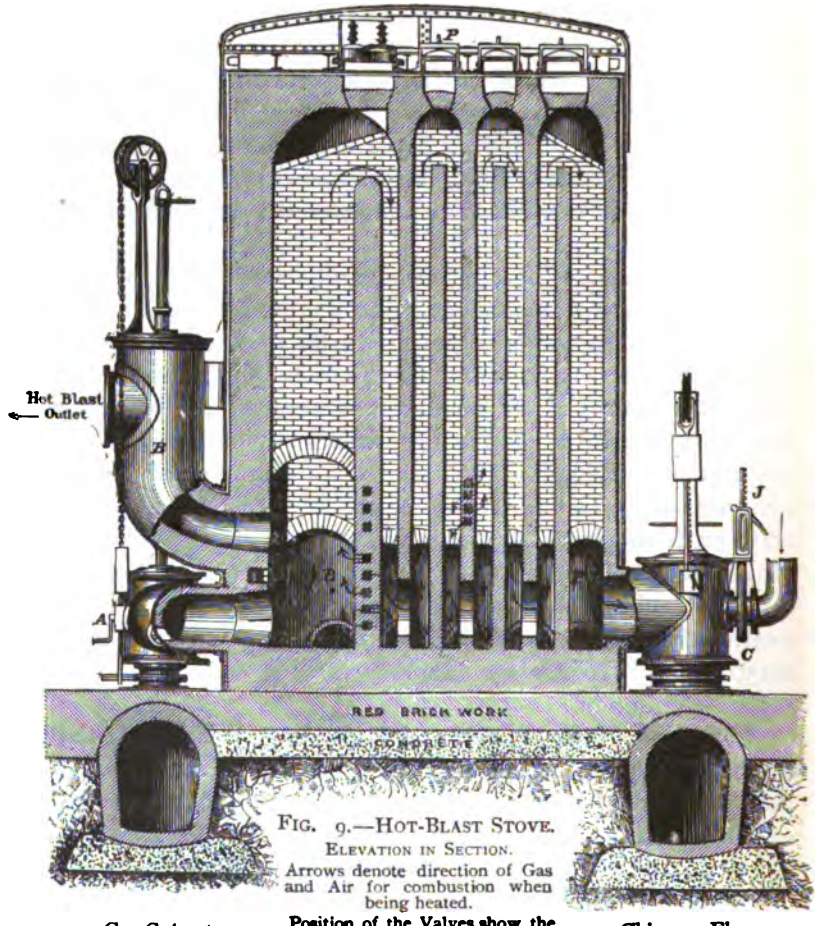


FIG. 9.—HOT-BLAST STOVE.
ELEVATION IN SECTION.
Arrows denote direction of Gas and Air for combustion when being heated.

Gas Culvert. Position of the Valves show the course of the Air when on blast. Chimney Flue.

The fire-brick stoves must usually be given two or three times greater area of heating surface than cast-iron stoves. The weight of brick used is about one ton (1,106 kilogrammes)

for each 20 square feet (1.8 square metres) of heating surface.

The Whitwell Stove (Figs. 9, 10) is a modification of the regenerative apparatus used in gas furnaces, and its

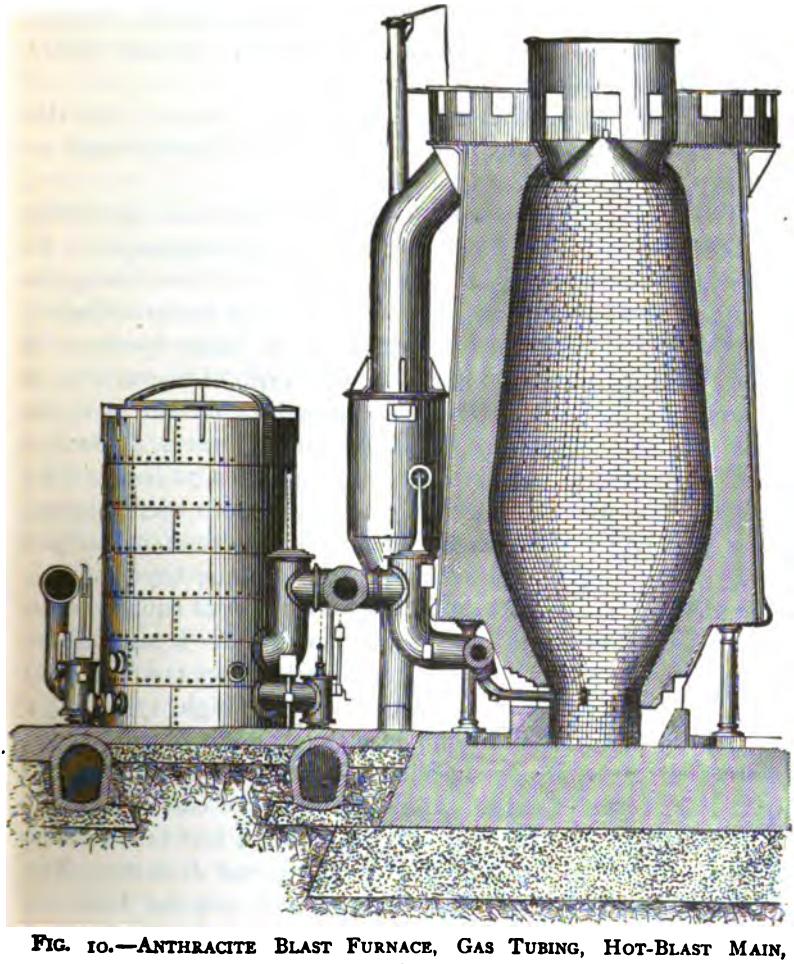


FIG. 10.—ANTHRACITE BLAST FURNACE, GAS TUBING, HOT-BLAST MAIN, AND STOVES.

method of operation is very similar. They are stated to bear the highest attainable temperature, to be free from lia-

bility to wear and tear, easily cleaned even when hot, free from leakage, to produce no loss of pressure of blast, to be very efficient regulators of temperatures, and to secure great economy over iron stoves. For a production of 600 tons (609,600 kilogrammes) per week, two of these stoves are fitted, each of about 3,000 cubic feet (84.945 metres) volume and of 2,000 to 2,500 square feet (185.8 to 232.25 square metres) of heating surface.

Blowing Machinery.—The blast is forced into the blast-mains by blowing machinery driven either by water or steam; the latter is the usual motor.

The steam cylinder and blowing cylinder are generally parts of one machine, which is called the blowing-engine. In the most common, and in some respects best, form the cylinders are vertical, the air cylinder above the steam cylinder, and the pistons have a common rod. A large fly-wheel is used to insure a uniform motion. The ratio of piston area is determined by the relative mean pressures on the two pistons. A blowing-engine having steam cylinders 45 inches (143 centimetres) diameter and air cylinders 72 inches (183 centimetres) diameter, making 14 revolutions per minute, took in about 200,000 cubic feet (5,632 metres) of air per hour and delivered it under a pressure, at the tuyeres, of 4 pounds per square inch (0.28 kilogrammes per square centimetre), drawing steam from four plain cylinder steam boilers 5 feet (1.5 metres) in diameter each and 36 feet (10.8 metres) long. The furnace was 66 feet (20 metres) high, 17 feet (5.1 metres) in diameter of bosh, had 5 tuyeres 6 inches (15 centimetres) diameter inside supplied with a blast heated to about 932° Fahr., (500° Cent.). The stoves were of cast iron, three in number, and contained, each, 24 pipes 14 feet (4.2 metres) long, and 9 inches (22½ centimetres) internal diameter. The speed of piston is usually, in Pennsylvania, not far from 225 feet (67.5 metres) per minute but rises to 300.

Blowing engines are often built with a beam mounted on columns and linked to the piston of a vertical steam cylinder at one end, and to that of a blowing cylinder at the other. Horizontal blowing engines are also sometimes built.

The *Winding-Drum*, when used, is usually turned by a pair of small, quick-working steam-engines. The rope is about ¾ inch (1.9 centimetres) in diameter, of steel or iron wire. A brake controls the drum and gives the attendant control of the platform when descending. All parts should be given a large factor of safety.

An inclined plane was formerly very frequently built for the hoistway, and the charges were raised in wagons running on rails.

The *Water-Bucket Hoist* consists of a set of timber supports and guides, at the top of which are pulleys carrying the rope or chain, which, at one end, is attached to the traveling platform or cage of the hoist, and at the other is secured to a large "bucket." Both bucket and platform are guided by the timber frame of the hoist. The bucket is alternately filled and emptied, receiving its water from a reservoir at the level of the charging floor and discharging its contents into another reservoir, or into a tail-race at the bottom of the hoist. The motion of bucket and cage is controlled by a brake, and latches at top and bottom hold them when they are to be kept stationary. The bucket and cage may be made of either wood or iron, the latter being preferred.

Water is supplied from some natural or artificial source, by gravity or by force pumps, or through hydrant pipes.

The supply-cock of the reservoir and the discharging-cock of the bucket are usually opened and closed by hand.

When the bucket is at the top, the cage is at the bottom of the hoist. When filled with water, the former overbalances the weight of the latter and its load, and, being unlatched, descends, pulling up the loaded platform with which it is connected by the rope or chain passing over the pulleys at the top. When the charges have been thrown into the furnace, the unloaded barrows are wheeled back upon the platform.

Meantime the bucket has been emptied, and the weight of the cage now preponderating, it descends, raising the empty bucket to the top.

This apparatus is simple in construction and durable, but

it is heavy, slow in operation, and quite bulky. It is much less used than formerly. From 20 to 50 per cent. of the whole energy of the water supply is wasted by friction and loss of head.

The *Plunger Hoist*, or water-pressure hoist, is a hydraulic press which either carries the platform directly or raises it through the intervention of pulleys and tackles. In the first, a strong hollow iron cylinder, of a length somewhat exceeding the height through which the platform is to be raised, is sunk into the earth in a vertical position. Water, under a pressure of sometimes 300 or 400 pounds per square inch (21 to 28 kilogrammes per square centimetre), is led from forcing pumps, or from an "accumulator," into this cylinder, and forces up a "plunger," which is fitted to the latter, and which carries the platform. The lower end of the cylinder is closed, the upper end is fitted with a stuffing-box, or a collar packing which prevents leakage as the plunger slides vertically through it.

The load at the plunger is equal to the weight of useful maximum load added to the weight of plunger and platform plus the frictional resistance to sliding, which varies somewhat, but which may be taken at one-tenth. Calling $W =$ the maximum load, and $W' =$ the weight of the moving parts of the hoist in pounds, $d =$ the diameter of the plunger in inches, and $p =$ the available pressure of water in the cylinder of the press in pounds per square inch,

$$d = \sqrt{1.1 \frac{W + W'}{\frac{1}{4} p\pi}} = 1.2 \sqrt{\frac{W + W'}{p}}, \text{ nearly.}$$

The accumulator consists of a heavily weighted plunger of considerable volume rising and falling under its load in a cylinder like that of the hydraulic press. A set of pumps driven continuously forces water into the accumulator, while it is drawn out intermittently by the working apparatus to which the water is supplied. This accumulator, or store-cylinder, must have such volume that it shall not be exhausted completely at any time, and its plunger must be loaded with the weight needed to preserve the maximum pressure desired.

By its use, small pumps and a small prime-motor acting continuously are enabled to supply water, which is drawn by the hoist in comparatively large volumes and intermittently, thus securing economy of maintenance, and, usually, of first cost. The accumulator is also useful as a safety-valve.

The connecting pipes should be made as large as is consistent with economy of cost, to reduce frictional losses. The velocity of the hoist is variable; one foot (0.3 metre) per second is a speed sometimes adopted. The expenditure of power at the pumps is frequently one-half greater than that usefully applied by the hoist.

An empirical formula for thickness of water pipes, used by some engineers, is

$$t = 0.000055Hd + 0.5,$$

in which d is the diameter, t the thickness in inches, and H is the total maximum head of water in feet; for thickness and diameter in centimetres and head in metres we have

$$t = 0.0018Hd + 1.5, \text{ nearly.}$$

Pipes with sockets are generally used, although flanged pipes are common.

The thickness of hydraulic press cylinders, and of pipes, also, may be taken by Barlow's formula, which gives an excess of strength:

$$t = \frac{rp}{f - p},$$

in which t = the thickness in inches, r = the internal radius in inches, p = the assumed bursting pressure in pounds per square inch, and f = the tenacity of the material in pounds per square inch.

For radius and thickness in centimetres, strength and pressure in kilogrammes per square centimetre, we have

$$t = \frac{r\ p}{f - p}.$$

The form of hydraulic hoist with which pulleys are used requires a shorter plunger, and one of larger area than that just described, the two dimensions varying in inverse ratio and proportionally with the velocity-ratio of the pulley combination. A small additional frictional resistance must be allowed for. This form is of less first cost.

The pressures used are limited by circumstances. The maximum, as determined by the ultimate safe pressures for the material used, are, in hydraulic presses, about 4 tons (630 kilogrammes per square centimetre) for ordinary cast iron, 6 tons (940 kilogrammes per square centimetre) when lined with copper, and from 7 to 10 tons (1,090 to 1,560 kilogrammes per square centimetre) when made of wrought iron or steel.

The *Pneumatic*, or *Air Hoist*, consists of a cylinder of proper size traversed by a piston, which is connected by ropes, carried over large pulleys, to the platform of the hoist. By a pressure exceeding that of the atmosphere, on the one side, or sometimes by the creation of a partial vacuum on the other side, the piston is caused to move through the cylinder, raising the load. The cylinder must be nicely bored, and the piston well fitted and carefully packed. The pressure adopted is usually that of the blast of the furnace, and the air is, in such cases, supplied by the main blowing engines.

The diameter of the piston may be calculated as for the hydraulic hoist. The efficiency of this hoist is greater. In one of the best designs of this form of hoist the working cylinder stands in the middle of the hoistway, and there is a platform on each side, both of which move together. In other forms the cylinder has the platform built around it. In some cases, hoists are constructed having two platforms or cages so arranged that, while one is ascending the other is descending, and vice versa, balancing each other.

For a furnace using 1,000 tons (1,016,000 kilogrammes) of material per week, the elevator, or hoist, would be calculated to carry two barrows of 500 pounds (227 kilogrammes) each, or about 1,000 pounds (454 kilogrammes) total, and the cylinder would be about 30 inches (762 centimetres) in diameter, as usually designed. The platform may be calcu-

lated to rise with greater velocity than that of the hydraulic hoist.

This is the most generally approved form of furnace hoist.

The *Steam Hoist* is of similar form, and is worked by steam taken from the boilers supplying the blowing and pumping engines. In this class the piston often forms a counterbalance to the platform, and is, if necessary, weighted.

The Water Supply of the blast-furnace is an important detail. Water is required for the tuyeres, for the steam boilers and the condenser, and, frequently, for the hydraulic hoist and other minor accessories.

It is necessary to secure such a supply that the furnace may not be interrupted in the dryest seasons. The required head is sometimes secured by a natural fall, sometimes by direct pumping, and sometimes by means of a large reservoir, at the required elevation, which is kept filled by forcing pumps. The water should be as pure as possible to avoid injury to boilers and to tuyeres by the formation of incrustation. Salts of lime are the most common impurities. They are removed to a greater or less extent, frequently, by heating, or by the use of chemicals, which render the precipitate pulverulent and readily removed, or which produce solutions which may be removed by occasional "blowing out" of the boiler, and which do not precipitate insoluble "scale."

The Steam Boilers are placed as near the engines as possible. The type may be, to some extent, a matter of choice, but they are usually of plain cylindrical form, set in brick-work, and fitted both with grates for use with solid fuel and with chambers and supply-conduits for gas from the furnace-top.

The extent of heating surface is determined by the quantity of steam required by the pumps and blowing engines. This amount is variable, but may be taken with ordinarily good machinery, as equivalent to about 35 pounds of water evaporated per hour per horse-power (15.64 kilogrammes per cheval). As a minimum, a square foot of heating surface for each six pounds of water (or about one square metre for each 30 kilogrammes) per hour may be given for solid fuel. With

gas, the lower temperature of fire usually compels the use of more boiler surface. One square foot of heating-surface to each two pounds (one square metre for each 10 kilogrammes) of water per hour is not unusual.

Cast Iron is the name given to the product of the blast furnace. It consists of metallic iron chemically united with carbon in proportions varying from two to nearly six per cent., silicon to the amount of sometimes five per cent., and usually manganese, phosphorus, and sulphur, in smaller proportions. Foundry irons also contain carbon in two forms, chemically united, forming a carbide, and mechanically mingled with the metal in the form of graphite. Minute quantities of calcium and other substances are also found in it. Analyses will be given hereafter.

The cast iron, when removed from the casting house, is assorted and sent to market in several grades. The darkest kinds of metal, which contain most carbon, are called foundry-pig, and the lighter grades forge-pig. The classification is usually as No. 1 Foundry, No. 2 Foundry, No. 3, or Gray Forge Iron, Mottled Iron, and White Iron.

The darker grades are used for castings, and the lighter for the manufacture of wrought iron.

The characteristics of the several grades of iron are thus summarized:

Foundry Irons.—No. 1 (Dark Gray Iron): Fracture dark gray, with high metallic lustre. Crystals large, with lustre resembling surface of fresh-cut lead. Makes fine castings; fuses easily; flows freely, is soft and rather ductile.

No. 2 (Gray Iron): Fracture gray; lustre clearly metallic; crystals smaller than preceding; a freely melting, free flowing, and moderately strong iron.

No. 3 (Light Gray Iron): Fracture light gray; crystals small; lustre dull; crystals larger and brighter near centre; makes best material for large castings.

Forge Irons.—No. 4 (Bright Iron): Fracture light gray; crystals small; lustre slight; too infusible and pasty for foundry use; makes good mill iron.

No. 5 (Mottled Iron): Fracture dull, silvery white; line

of whiter iron around edge of fracture; speckled with gray within; hard, brittle, but sometimes a good forge iron.

No. 6 (White): Fracture silver white; often bright; granulated texture, with radiating lines of crystallization; extremely hard and brittle; useless except for low grade puddled iron.

The properties of cast iron will form the subject of a succeeding chapter.

The Bloomary, or Catalan Process.—The reduction of ores of iron is sometimes practiced by other methods than that already described. The most common is that known as the Bloomary, or the Catalan Forge Process. It is practiced in Spain, as indicated by its name, in Sweden and Germany, and perhaps other parts of Europe, and, in a rude way, in Asia and Africa, as already described page 46.

The product is wrought iron or steel in masses called "blooms," which vary in size with the size of furnace, up to 300 or 350 lbs. (136 to 159 kilos) in weight.

The process can be made commercially successful in districts in which very rich ores and abundance of wood for charcoal can be obtained and at low prices.

The furnace usually consists of an open hearth of about 28 inches (70 centimetres) depth to rear wall, and 30 inches (76 centimetres) width, and with tuyeres inserted 2 feet (0.6 metres) below the level of the top of the mass of fuel.

The casing is of cast iron, double and supplied with water, to keep it from becoming overheated. Above the hearth a stack is built to carry away the products of combustion. The hearth is open at the front like an ordinary open fireplace. The blast is supplied under a pressure of from 1½ to 2 pounds per square inch (0.11 to 0.14 kilogrammes per square centimetre), and heated to a temperature rarely if ever measured, but generally supposed to be 600° to 800° Fahr. (316° to 426° Cent.). The heating pipes are siphon tubes placed in the stack.

The tuyeres are either pointed horizontally or slightly inclined downward, and have a segmental opening for the better distribution of the blast.

In working ores by this process, the furnace is filled with

charcoal, the fire lighted, and the blast turned on. When the whole is well ignited, the ore, calcined and coarsely pulverized under stamps or breakers, is sprinkled with a shovel over the surface of the mass of fuel in small quantities, and at short intervals basketfuls of charcoal are added as the fire burns down. The ore is deoxidized by the carbon of the fuel as it works downward, and the metal finally aggregates in an unfused pasty mass of agglutinated grains at the bottom of the hearth, like a great sponge. The cinder fills its pores and surrounds it as a liquid bath, and is tapped off occasionally at the front.

A "loup" weighing about 300 pounds (136 kilogrammes) is formed in about three hours. This is lifted out from under the mass of fuel and is worked under a hammer of about 5,000 pounds (2,272 kilogrammes) weight into a billet or bloom, being reheated, when necessary, at the bloomary fire.

The men work in two "shifts" of twelve hours each, and each fire is expected to yield from one ton to 2,500 pounds (1,136 kilogrammes) per day. The amount of fuel used varies from 200 to 300 bushels (5,664 to 8,496 litres), 3,500 to 5,000 lbs., per ton (1½ to 2½ kilogrammes per kilogramme), according to the skill of the iron-maker and the quality of ore and fuel. The total cost of the bloom is not far from that of puddling iron. One ton (1,016 kilogrammes) of finished metal requires from 1½ to 1¾ tons (1,524 to 1,778 kilogrammes) of selected ore, which is equivalent to from 2½ to 4 tons (2,540 to 4,064 kilogrammes) of ore as mined.

The American Bloomary Process, for making iron direct from the ore, is a modification of the old German process, although it is in many places incorrectly spoken of as the Catalan Process. Like the Catalan, it is adapted to rich ores of iron that are free from all impurities save gangue, which, before entering the furnace, must be removed as far as possible. Ores to be profitably worked by this process usually contain above 90 per cent. of magnetic oxide of iron. The ore is by this method roasted, crushed, and then subjected to this process. The furnace is composed of cast-iron plates 2 or 3 inches (5 to 7.5 centimetres) thick joined together, form-

ing an open box, which, at the base, is from 24 to 30 inches in its length (61 to 76 centimetres) at right angles to the tuyere, while the dimensions are 27 to 32 inches (68 to 81 cm.) laterally. In the rear, parallel to the tuyere, it is from 28 to 36 inches (71 to 91 cm.) deep. In front, however, it is from 15 to 19 inches (38 to 48 centimetres), to make room for the "fore plate." This rectangular space is known as the "fire box," and it is here that the reduction takes place. The air pressure is from 1½ to 2 pounds per square inch (0.11 to 0.14 kilogramme per square centimetre). The stack, through which the products of combustion and gases pass, is of rectangular section and of sufficient size to receive the whole furnace under it. This stack is about 20 feet high (6.1 metres).

The higher the temperature of the blast the less fuel consumed. It ordinarily varies from 600° to 800° Fahr. (316° to 426° Cent.), but it has been found that by raising the temperature of the blast, the tendency for the impurities present to enter into the iron is increased.

One "D"-shaped tuyere is used, made of ½-inch (1.27 centimetres) wrought iron. The nozzle is about a foot (18 centimetres) long, and is inclined at an angle of about 15°. If this angle is too low, the capacity of the furnace is diminished by the coal forming a crust on the bottom; if it is too high the blast cuts through the loup. The ordinary cost of a furnace such as is described here is about $600. The remainder of the process closely resembles the Catalan. The amount of fuel used is from 300 to 350 bushels (8,496 to 9,912 litres) of charcoal per ton of iron. A ton is said to have been produced with an expenditure of 240 bushels (6,796 litres). The production of a furnace of the size described averages 1 ton (1,016 kilogrammes) in 24 hours, or about 300 tons (304,800 kilogrammes) in a year.

The Siemens Process of reduction of ore, or "Direct Process," as this method is termed, is one which has attracted much attention, but one which is not yet generally introduced. In this process the ore and flux are fused together in the reducing flame of the regenerative furnace,

and the cinder is tapped off at intervals, leaving, finally, the molten iron on the hearth, to be drawn off into ingot moulds. The process occupies four or five hours, and the product consists of four or five tons of wrought iron or steel.

In the latest modification of this process Mr. Siemens avoids the serious difficulty attending the reduction of an ore on the hearth of the reverberatory furnace by effecting the change in a rotating cylinder similar to the rotating puddling furnace, to be hereafter described, and by adopting a peculiar composition for the lining.

CHAPTER IV.

THE MANUFACTURE OF WROUGHT OR MALLEABLE IRON.

Wrought Iron is distinguished from cast iron, chemically, by its comparative freedom from carbon, silicon, and other elements which enter into the composition of the product of the blast furnace to such an extent as to form an important part of the latter material, and by its greater strength, ductility, and homogeneousness. It has immensely greater value as a material of construction. Its peculiar properties will be considered at length in a succeeding chapter devoted to that subject.

It may be manufactured by the direct reduction of the ore, as in the bloomary, the Siemens and the other "direct" processes already described; but by far the greater part of the wrought iron which appears in the market is made from cast iron by the removal of carbon, silicon, and impurities by the process of refining and puddling, and is worked into marketable shape by rolling or by hammering.

Very large quantities of a metal which resembles wrought iron closely in chemical composition and in mechanical properties—and which is properly classed with malleable or wrought iron—is made by the pneumatic, or Bessemer process, and by the Siemens-Martin process, and sold in the market as "low steel," "Bessemer steel," or "Siemens-Martin steel," or, as lately proposed, under the name of "ingot iron."

These processes of manufacture will be described in a chapter on the manufacture of steel.

The Decarbonizing Process consists in the subjecting of molten cast iron to the oxidizing flame of a reverberatory furnace until the carbon has been burned out and the metal is sufficiently pure to become pasty, and to cohere in spongy masses at the maximum temperature of the furnace.

For these processes, the lighter grades of cast iron are selected as containing least carbon, and therefore demanding less labor, and as they are cheaper than the dark, foundry grades.

Cast irons containing sulphur and phosphorus are less valuable than irons free from these elements, as the former yield a malleable iron which is brittle and difficult to work and to weld at high temperatures, and the latter make the product brittle and non-ductile when cold. Manganese, from its chemical relations as an antidote to sulphur, is a desirable ingredient. All other foreign substances are undesirable. The carbon and silicon are removed during the process of conversion; the sulphur is partly driven off, as is manganese; the phosphorus is retained in the iron.

The earliest processes of making wrought iron were, as already stated, direct processes. The earliest process of reduction of cast iron, and that which was practiced at the time of the invention of puddling by Cort, is still practiced, and is known as the Refinery or Forge Process.

The Forge Process is, in method of working, similar to the bloomary process, and the forge fire is constructed very much as is the bloomary.

Instead, however, of reducing ore by expelling its oxygen in presence of an excess of carbon, the forge process burns out carbon from cast iron in presence of an excess of oxygen.

As practiced in the United States, where the process is adopted to a limited extent in making blooms and billets to be worked into boiler-plate, it consists in melting down pig-iron on a shallow hearth under a blast until about 250 pounds (113 kilogrammes) is collected under the tuyeres. The molten mass is stirred with an iron rabble and the blast kept on it until, the carbon having been burned out, the iron becomes pasty and adherent, and can be worked into a ball. The cinder which collects as the impurities are worked out, is now and then tapped off. When steel is made by this process the cinder is retained, and the ball is worked in a bath of the molten slag. When ready to "ball up," the temperature of the fire is raised, the metal worked over to free it from cin-

ders, and then balled up and removed from the fire to be worked into billets or blooms.

One fire worked twelve or thirteen hours per day by a single shift of hands, produces five or six "loups" weighing about 200 pounds (91 kilogrammes) each. If the iron has been refined previously, as described in the succeeding article, the production is sometimes doubled. The consumption of pig-iron and of charcoal in this process is about 1,800 and 2,400 pounds (817 and 1,090 kilos) respectively. The greater number of forges of this kind in the United States are in Pennsylvania. The process is adopted, to some extent, in Sweden, Germany, and other parts of Europe. In a large number of cases, establishments started as bloomaries have been changed into forges for the reduction of malleable from cast iron.

Refineries are forges in which the process just described is interrupted when but a portion of the carbon and other oxidizable substances are removed from the cast iron.

The refinery is usually larger than the forge above described, measuring 3½ feet (1.06 metres) wide to the back, 5½ feet (1.67 metres) long, and its hearth has a depth of a foot or eighteen inches (0.304 or 0.456 metre). From one to two tons (1,016 to 2,032 kilogrammes) of pig-iron can be melted down and retained in it. The large size of the hearth compels the use of four or more tuyeres.

The metal is sometimes run into the refinery from the blast furnace, and sometimes charged in pigs and melted in the forge. The metal, subjected to the action of the blast, "boils," and gradually loses carbon, and is finally tapped off on the casting-floor, or into moulds, in which it assumes the form of flat plates about ten feet (3.04 metres) long, three feet (.91 metre) wide, and two inches (5.08 centimetres) thick. These plates are broken up and used in the forge or in the puddling furnace.

Each charge requires about two hours for complete refining.

The loss of iron is from 8 to 20 per cent., according to the skill of the workmen. The usual loss is about ten per cent.

The expenditure of fuel is about one part to five parts of iron in good work. This "finery furnace" is also called a "running-out fire." One fire will refine from 10 to 20 tons (10,160 to 20,320 kilogrammes) of metal per day. Either coke or charcoal may be used as fuel.

The "fine metal" is a white cast iron, from which nearly all silicon, a large part of its carbon, and much of its manganese and sulphur, as well as some phosphorus, have been removed. The slag, which contains those substances which are not volatilized, is a silicate of iron containing about 53½ per cent. iron oxide, and 14½ per cent. silicon, and 32 per cent. oxygen, the formation of the silicate involving a serious loss of iron.

Puddling and Boiling are modifications of the same process, and in both the refining, as already described, is carried on until the character of the metal is entirely changed, and the product is obtained which is known as malleable or wrought iron.

In the manufacture of malleable iron by these processes, the metal is melted as in refining, but the fusion takes place on the hearth of a reverberatory furnace in which the metal only comes in contact with the gaseous products of combustion, and is thus less exposed to contamination by the deleterious elements found in fuel, and the necessity of a powerful blast to secure a supply of air is avoided. Draught is secured by a moderately tall chimney, or by a fan-blower, and controlled in the former case by a damper on the chimney-top.

While the metal lies in the molten state on the hearth the puddler stirs it with an iron rabble, and thus brings every portion in contact with the decarbonizing flame. This oxidizing action of the air is seconded by the presence of fluxes rich in oxygen, such as magnetic hematite ores, or scales from the blacksmith's forge. Slag and cinder, rich in iron oxide, are sometimes used where they can be obtained free from sulphur and phosphorus, or where the puddled iron is of a cheap grade.

In "dry-puddling" the puddler relies upon the action of

the air principally; in "wet-puddling" the work is largely done by the oxides used in "fettling." The first method is usually called, simply, puddling, the latter is often known as "boiling," or as "pig boiling."

The form of reverberatory furnace ordinarily used in the puddling process, is illustrated by Fig. 11.

The hearth, *A*, is made, usually, of plates of cast iron, carried on brick walls or on short iron pillars, *bb*. It is usually about five or six feet (1.5 to 1.8 metres) in length, and four feet in width, opposite the charging door. This hearth is covered thoroughly with slag, or with a "fettling" of iron oxide, which is melted down upon it to protect the plates from the solvent and corroding action of the charge.

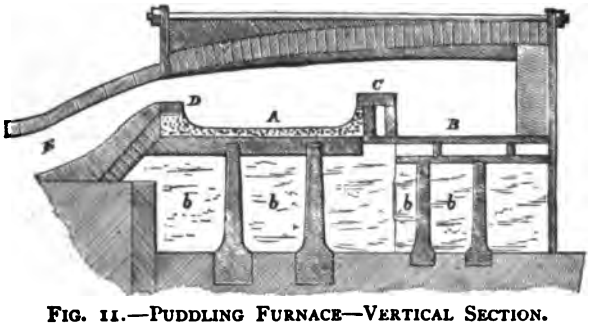


FIG. 11.—PUDDLING FURNACE—VERTICAL SECTION.

The fire is built, usually, of bituminous coal, in the fire-place, *B*. The grates are generally single square rods of iron separately detachable. They can be removed singly to clean any part of the fire, or replaced when any one of them is burned out or droops under excessive heat.

The area of grate is usually six square feet (0.56 square metre), and sometimes ten feet (0.93 square metre), or more, its precise dimensions being determined by the character of the metal used, of draught, and of fuel. Between the grate and the hearth is a fire-brick wall, or "bridge-wall," *C*, extending from side to side, rising sufficiently high to prevent any portion of the fuel passing over on the hearth or any molten iron falling over upon the fuel.

Resting upon and extending around the sides of the hearth is a box, or a double wall of cast iron, eight or ten inches (20 to 25 centimetres) high, through which hollow box

water circulates, preventing its fusion. The iron bottom is also sometimes double and similarly kept cool. Air is sometimes substituted for water as a cooling medium. The sides, like the bottom, are carefully protected by a coating of slag and ore laid on under so high a temperature that it may be readily moulded.

At the end nearest the chimney, the hearth terminates at a second bridge or "altar," *D*, which prevents the overflow of the molten metal at that end. Beyond this bridge-wall, the furnace flue inclines downward and terminates at the chimney flue, *E*, the cross-section of which is usually given 20 per cent. of the area of the fire-grate. At the foot of the incline is an opening out of which the molten slag passes after leaving the hearth and overflowing at the altar. On the side of the furnace, opposite the middle of the hearth, is the working door. It is about 20 inches (51 centimetres) square, and is closed by a slide lined with fire-brick, which is arranged to rise and fall vertically, and is counterbalanced. A small opening at the bottom of the door, large enough to admit the puddler's rabble, permits the workman to stir the charge without serious discomfort, and without admitting cold air to chill the furnace and check the draught.

The roof of the furnace is an arch of fire-brick, about two feet (0.6 metre) high at the fire-place, and sloping gradually, until, at the chimney, it is less than a foot above the bottom of the flue.

Outside the furnace, at the opening at the foot of the chimney—the floss-hole—a fire is maintained to keep the escaping cinder fluid until it has fairly left the furnace. In some furnaces a charging-door is placed near the altar, through which the pig-metal is placed "on the bank" to be melted down.

The original process, as practiced by Cort, the inventor, was that of dry puddling. He made up his furnace-bottom with quartz sand, and used iron containing little carbon, removing that remaining by the oxidizing action of the flame alone. Refined iron, and the white and mottled grades, are generally used in this process, as they promptly become

decarbonized, assume a pasty condition, and can then be balled up. The cinder-bath is produced by the union of the silica present with iron-oxide. The loss of metal is variable, but may be taken at an average of nearly ten per cent. In the time of Cort a furnace could be made to produce but about ten tons (10,160 kilogrammes) per week. Subsequent improvements, including the ventilated bottom, doubled this quantity.

In the Boiling Process, or that of "wet-puddling," the furnace is made rather deeper than for puddling. Rich cinder is used for fettling, and is charged into the furnace, and mingles with the pig-iron, its oxygen taking up the carbon of the iron, and thus hastening the process of decarbonization, the melting and molten iron lying in a bath of fluid cinder.

Unrefined iron can be worked by this method, and instead of losing iron, if the process is well managed, some gain of weight is made by reducing the oxide charged, and the fettling of the furnace. The first process, often called simply puddling, is in use in making low grades of iron from white pig-metal. In the boiling process, No. 3 pig-metal is generally used, but sometimes gray pig, and in other cases, refined iron.

The charge of the puddling furnace is about five hundred pounds (227 kilogrammes) of pig-metal, which is laid carefully on the bed of the furnace, or broken up and piled on the bank and around the sides. In the boiling process, the necessary amount, 100 pounds (45 kilogrammes), more or less, of cinder, or ore, and hammer-scale is added.

The door is then closed, and the damper opened wide, and the charge is melted down, the puddler moving the pieces among each other to secure a regular and not too rapid fusion, and to give the flame free access to the metal. Fusion commences in fifteen or twenty minutes, and in a half hour the charge lies in a molten pool on the hearth, and assumes a pasty condition. The puddler stirs the fluid mass with his rabble, checking the draught to give more time for completing the chemical reactions, and even chills the metal by throwing water upon it. The heat is again increased, and

the intermingling of iron and cinder produces a rapid union of oxygen and carbon, and this evolution of carbonic acid and oxide produces rapid "boiling" and frothing. The lining of the furnace yields oxygen also by the reduction of the oxide of which it is composed.

The boiling soon ceases, and small masses of reduced iron appear here and there. In an hour or more from the commencement, the whole mass is an aggregation of pasty grains, and the puddler, raising the temperature of the furnace to its maximum, works the iron which has been "brought to nature" into a half dozen spongy masses of convenient size, weighing about sixty to eighty pounds (27 to 36 kilogrammes) or more each, meantime working his fire until a smoky flame appears, and thus he secures the now nearly pure iron from oxidation. The balls thus made are heated up to welding temperature, well worked and compacted, and finally removed from the furnace.

Using gray iron, six heats are made in twelve hours; with white iron seven can be made. The loss of weight of pig amounts to under ten per cent., and the fuel used amounts to about one ton or kilogramme of coal per ton or kilogramme of iron made by the process of boiling. With refined iron, the consumption of metal is about 2,300 pounds per ton (1,044 kilogrammes per 1,016 kilogrammes), and of fuel about ¾ ton (762 kilogrammes). Two men are employed at each furnace, the puddler requiring an assistant to manage the fire, and to aid in lifting the iron into and out of the furnace. The best work is done when the iron is puddled in small quantities.

The Principles and Theory of Puddling are evidently very simple. Urbin divides the process into five periods: that of fusion; that of purification; that of refining to produce grain; that of carbonizing the grain, and that of final refining by the flame.

While melting, a part of the metal is oxidized, and the resulting oxide unites with the cinder present in decarbonizing the remainder of the charge. The decarbonization produces nearly pure iron, and after refining the grain the proc-

ess of recarbonizing may go so far as to produce a puddled steel. The extent of this recarbonizing, and of the final refining under the flame, determine whether the product shall be a kind of steel or a malleable iron.

The office of the oxides used, as slag, cinder, scale, or iron ore, is to oxidize the carbon and impurities present in the pig-metal. The bath formed of these substances surrounds and permeates the grains of reduced iron toward the end of the process, and the richer in iron, the more completely does it answer the purpose of giving a fine grain. It must, however, contain a sufficiently moderate quantity of metal to permit the formation of protoxides. If sufficiently basic, yet rich in iron, it will cause a moderately slow decarbonization, will be fluid enough to permit very free circulation of the grains of metal when formed, and will be readily separated from the sponge when the puddle balls are made up.

The best cinder will be fluid and white in color. It chills quickly in the air, and has a peculiar greasy appearance. If too acid it will usually have a red tinge, will be quite fluid, and will solidify quite slowly outside the furnace.

In selecting and mixing the metal to be charged, the design should be to secure a uniform character of product and good quality. The best pig metal will make the best wrought-iron. Irons of very different quality cannot usually be worked well together.

The cinder charged is usually obtained from under the hammer as scale, or from the rolls; it is liable to produce an injurious effect by returning to the metal objectionable ingredients, and by making the iron work dry. Wrought scrap is often used in making up the charge. It should always be added in small pieces, such as can be easily handled by the puddler with his rabble.

By proper management of the fire, the puddler obtains either an oxidizing or a carbonizing flame. The character of the flame is not only important as modifying the action of the gaseous current on the iron directly, but, by reaction, upon the slag.

In puddling pig metal containing sulphur or copper, lead

or zinc, more time is required than with pig free from these impurities. Some waste is likely to arise from this increased time, which permits greater oxidation. The slag contains the wasted iron as ferrous and manganese silicates and magnetic oxide, and is charged with the sulphur and phosphorus removed in the states of sulphide and phosphate, and the loss of iron is supposed to be always increased with increase in the proportion of these separate impurities. The presence of manganese has, nevertheless, been shown by Caron and others to be useful by its counteraction of deleterious effects of sulphur, as in the pneumatic process. As the silicate of iron, which forms the body of the slag, contains between three and four times as much iron as silicon, the existence of an excess of silicon in the pig metal involves serious loss of metal in puddling. The removal of 3 per cent. silicon would cause a loss of about 10 per cent. iron. The time required for removal of carbon is given as follows:

PROGRESS OF DECARBONIZATION.

	Time.	Carbon.	Silicon.
Pig Metal Charged.....	12 M.	2.275	2.720
Sample No. 1.....	12.40 P.M.	2.726	0.915
Sample No. 2.....	1.00 P.M.	2.905	0.197
Sample No. 4.....	1.20 P.M.	2.305	0.182
Sample No. 6	1.40 P.M.	1.206	0.163
Sample No. 8.....	1.50 P.M.	0.772	0.168
Puddled Bar, 9.....	.....	0.296	0.120
Wire-rod, 10.....	.....	0.111	0.088

It is seen that the silicon is nearly all removed before the carbon is attacked and during the first period of low temperature, and that the removal of the carbon occurs rapidly during the second half of the process. Siemens has shown that no silicon is taken up by fluid cast metal in contact with silica or silicates, and has stated that the removal of the silicon and carbon is due to the action of the oxides contained in the cinder alone, which oxides are decomposed, yielding the oxygen to the carbon, and adding to the bath the iron thus reduced. This indicates the wastefulness of the dry process, as above

shown, and the comparative economy of wet-puddling or boiling. The loss of metal in the first, or the amount of oxide needed in the second, is thus calculated, the formula for the oxide being Fe_3O_4, and the atomic weight, 232. The atomic weight of the iron is $3 \times 56 = 168$, and hence there is required, in weight of oxide, $\frac{232}{168} W = 1.4W$, where W represents the weight of iron to be reduced, and an equal weight is needed to form the bath of cinder. It is vastly cheaper to supply this as oxide than to oxidize the metal on the hearth.

The quantity of heat carried away by the water circulating through the water bottom and the sides of the puddling furnace has been found, by experiment, to amount, in some cases, to but about 60,000 British thermal units (15,000 calories) per hour.

The gases discharged from the common form of puddling furnace are at so high a temperature that a vast quantity of heat is necessarily lost. The heat needed for melting one ton of metal is less than that obtained from 150 pounds (68 kilogrammes) of good coal. As already shown, the immense loss here experienced can be reduced by increase of temperature of fire, or by utilizing waste heat, as in the Siemens furnace, or in heating steam boilers.

New Methods of Puddling, and especially methods of *mechanical puddling*, which are intended to supersede the usual method of working the bath with the rabble in the hand of the puddler, are little practiced.

Many devices, in which the puddler's rabble is worked by machinery, have been invented, but, although adopted to some extent in Europe, none have come into extensive use. It has usually been found necessary to employ the same number of workmen as before, and the expense of the building and maintenance of the machinery is considerable. The quality of the product is rarely as good as when the puddling is done by hand.

Siemens has puddled iron successfully in the reverberatory furnace under the neutral flame of the regenerative furnace, the requisite oxygen coming entirely from the cinder and fettling. He has turned out 18 heats in 24 hours, effecting

reduction entirely by the cinder, his yield exceeding the charge in quality and weight.

In the Henderson Process, which is one of the most promising, the process of manipulation is nearly the same as in ordinary boiling, but the inventor introduces a peculiar cinder, by the addition to the bath of a flux containing fluor spar and titaniferous iron ore. Impurities pass off as volatile fluorides. Pig-iron, containing nearly 1.5 per cent. of phosphorus, has been made into wrought iron, proven, by Kirkaldy, to be of excellent quality. Iron made from pig containing 0.91 per cent. of phosphorus, was found to contain, according to analysis by Williams, but 0.09 in the finished metal. In other instances the proportion was reduced from 1.35 to 0.04 per cent. Pig-iron, containing considerable sulphur, was made into puddled iron containing but a trace.

In the Ellershausen Process of refining metal to be used in the manufacture of puddled iron, the stream of molten iron issuing from the blast furnace is led along troughs lined with oxides, and, by the same reactions which occur in refining, the carbon and silicon are partially removed.

The most generally introduced, and, as thought by many engineers, the most promising improvement, is the introduction of rotating or revolving furnaces, such as have been devised by Danks, Sellers, and Siemens.

Rotating Puddling Machines are a form of puddling furnace in which the metal is agitated by the revolution of the furnace instead of by the puddler's rabble. The general plan is very old; but the first invention of this class to obtain an extended trial was that of Samuel Danks, of Pittsburgh, Pennsylvania; it has been introduced, with varying success, both in the United States and Europe. This apparatus (Fig. 12) consists of a cylindrical vessel, *A*, 4 feet (1.2 metres) or more in its internal diameter, and of nearly the same length, mounted on rollers in such a manner that it can be rotated by means of gearing. It is open at each end and receives the flame from a furnace, *B*, at one end, and delivers the gases to a chimney flue, *C*, at the other end.

A fan-blast supplies oxygen above as well as below the bed

of the fuel. The part of the chimney flue next the barrel of the furnace is detachable and can be swung aside to admit the charge of metal, or to permit the introduction of a rabble, or of the tongs used in removing the puddle-ball. A crane, *D*, takes its weight.

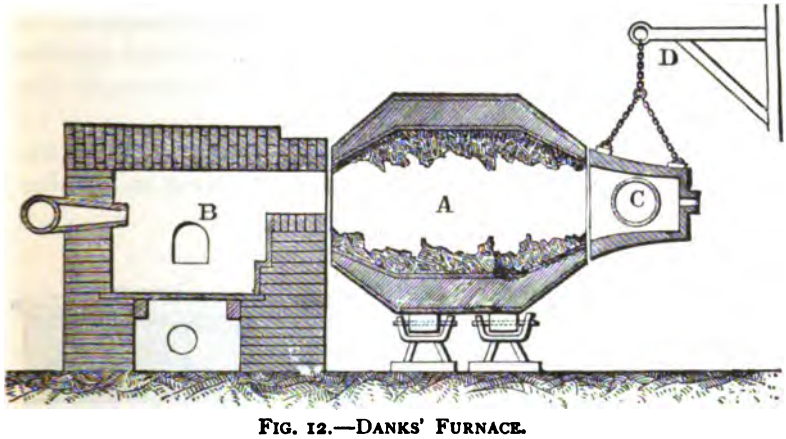


FIG. 12.—DANKS' FURNACE.

The barrel of the furnace is of iron and constructed of staves hooped with strong wrought-iron bands. It is lined first with a paste of pulverized iron ore and clean lime, and, after this has set, with a fettling of iron ore fused in place while the furnace is slowly revolving. This lining weighs from 2 to 3 tons (2,032 to 3,048 kilogrammes) in furnaces capable of taking 600 to 750 lbs. (272 to 341 kilos) at a charge.

The furnace is either charged with solid pig-metal, or with molten cast iron from a cupola. The barrel is revolved, when the charge is perfectly fluid, once or twice a minute. When the iron begins to thicken, toward the end of the process, the motion of the furnace is stopped, and the cinder is tapped off at so high a temperature, that it is very fluid. The furnace is then started, and driven at a speed of six to seven revolutions per minute, until the violently agitated iron becomes pasty. Speed is again reduced to two or three revolutions per minute, and the sponge is thus worked

into a ball, which is removed by means of a fork carried in slings by a crane. Refined metal is puddled in 35 minutes after melting. The puddle-ball sometimes weighs 1,000 pounds (454 kilogrammes) or more, and the charge of pig-metal as much as 2,000 (909 kilogrammes). The machinery for working it into bar is necessarily specially designed to handle these great masses. Spencer and Crompton, in Great Britain, and other inventors, have introduced modifications of this furnace. Siemens has used a furnace of this class in making iron direct from the ore.

The Rotating Puddling Machine of Messrs. Sellers & Co. (Fig. 13), is an egg-shaped rotating vessel, having an opening

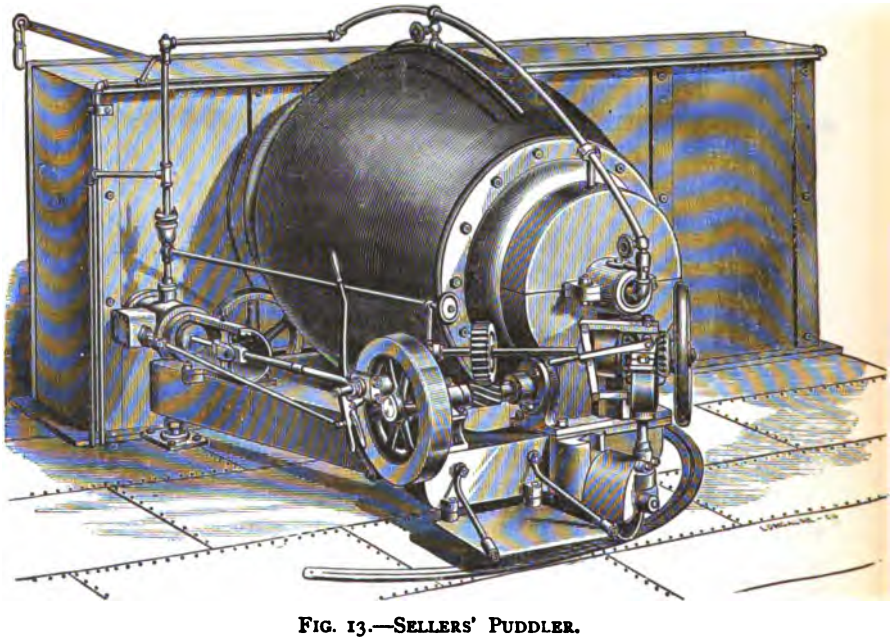


FIG. 13.—SELLERS' PUDDLER.

only at one end, through which the flame from the furnace enters at its upper side, and issues below, after eddying over through the revolving chamber, which is mounted on a set of friction wheels at each end. The whole system, including

the steam-engine by which it is rotated, and by means of which also the vessel is caused to swing horizontally through an arc of 90° when it is to be charged, or when iron is to be removed, is mounted upon a platform pivoted at the end nearest the flue, and sustained by wheels traversing a set of tramways on the floor.

Friction clutches throw the engine into gear when it is designed either to revolve the "bowl," as the vessel is sometimes called, or to turn the vessel into position for charging or working. The gas used for heating this furnace is supplied by gas-producers, and rejected heat is economized by regenerators. Heat issuing through the wall is intercepted by a water back.

The iron to be puddled is usually charged molten, from a cupola. The process of puddling is similar to that practiced with the Danks furnace, but the higher temperature of the furnace gases, and their greater uniformity of character and purity, are claimed advantages, as are those due to the peculiarities of design. The ability—secured by the use of these furnaces—to handle large masses with economy of labor and convenience, is the most marked of their advantages.

In the above-described furnace, the chamber revolves in the vertical plane. In other and later forms, as Ehrenwerth's and Pernot's furnaces, this revolution takes place in the horizontal plane.

Mansley's (British) and Ehrenwerth's (Bohemian) machines are reverberatory furnaces, in which the hearth is circular in form, detached from the body of the structure, and mounted upon a vertical shaft, by means of which it can be set in motion rotating in the horizontal plane. The joint between the hearth and the adjacent parts of the furnace is closed by a water-seal, the edge of the hearth carrying a flange, which dips into a circular water-trough attached to the furnace. In this furnace the molten metal is stirred by broad-bladed rabbles, held by the workman or by mechanism, as may be thought best. The charge weighs from three-quarters of a ton to one ton (762 to 1,016 kilo-

grammes). The power required to rotate the hearth 20 to 25 times per minute is given as ½ to ¾ horse-power.

A saving of fuel, time, and capital, the health of the puddler, and a peculiar uniformity of product, are advantages claimed for these furnaces.

Pernot's Puddling Furnace is quite similar in form to the preceding, but the plane of revolution of the "pot," or basin-

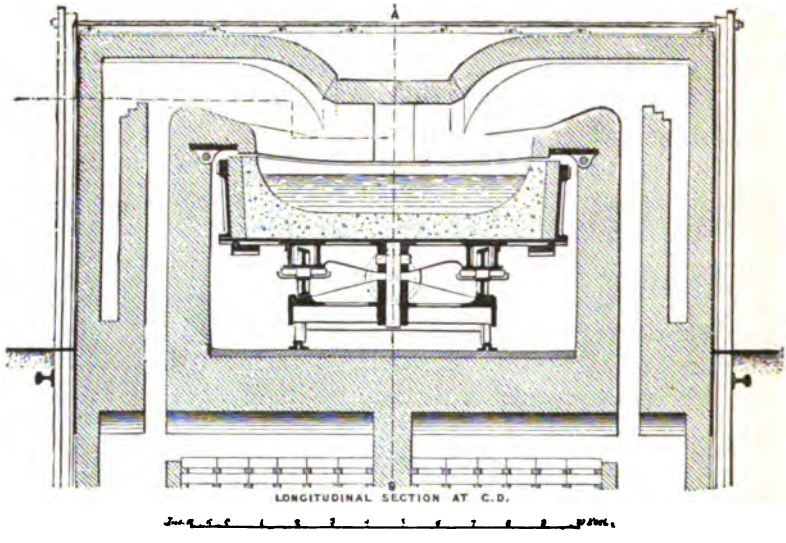


FIG. 14.—PERNOT'S FURNACE.

shaped hearth, is inclined at an angle of 10° or 15° from the horizontal, the lower side being next the charging door. The pot is kept cool by the circulation of water through its double sides and bottom. A fan-blast is used. The inclination of the pot causes a flow and intermixture of the molten metal, like that in the Danks type of furnace.

The retention of the ordinary form of reverberatory furnace permits the use of a charging door, as in the ordinary furnace, and this combination of the two details affords exceptional opportunity for working the charge, and for dividing it into any convenient number of puddle-balls. One

of the most important of the advantages of this type is, that the pot may be mounted on a movable carriage, and then arranged to be wheeled bodily out of the furnace and back again, when the lining requires repairs, thus saving the time usually lost in waiting for the furnace to cool.

A furnace having a hearth 7 feet 10½ inches (2.4 metres) in diameter, takes a charge of one ton (1,016 kilogrammes).

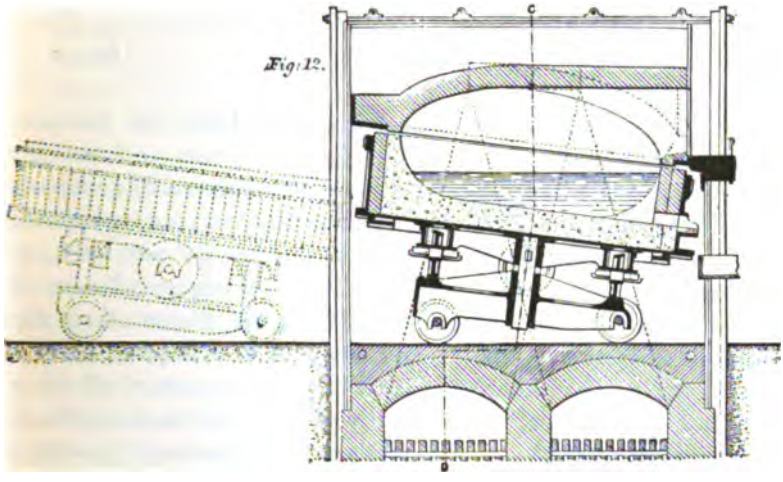


FIG. 15.—PERNOT'S FURNACE.

Four, and sometimes five charges of pig-iron can be worked in twelve hours, and each charge is worked into from fourteen to twenty balls. One furnace puddles 8 or 9 tons (8,128 or 9,144 kilogrammes) from refined iron in twelve hours, losing one-third as much iron as is lost with the ordinary furnace, and with a saving of 20 to 25 per cent. of fuel. With common pig-metal the saving is greater, sometimes reaching 33 per cent. This furnace is used in making steel.

The following statement gives the cost of puddling, as reported by the Home Iron Works, 1874:

COST OF PUDDLING (DURFEE).

Ordinary Process.			Rotating Furnace.	
Pig-metal	1.654 tons,	$27.73	1.061 tons,	$25.68
Fuel coal	1.002 tons,	3.78	0.703 ton,	2.46
Wrought iron scrap	0.019 ton,	0.42	0.057 ton,	1.00
Hammer slag	0.025 ton,	0.10	0.078 ton,	0.32
Labor		3.35		3.35
Repairs		1.18		1.18
Miscellaneous		1.52		1.63
		$38.08		$35.62
Deduct scrap bar				.65
				$34.97

The Puddle-Ball, as withdrawn from the furnace, is a spongy mass of iron, of which the pores and smaller cavities are filled with liquid cinder. The chemical composition of the mass is therefore neither uniform nor otherwise satisfactory. The ball contains iron, generally almost completely decarbonized, and mingled with an impure silicate of iron, into which has passed nearly all the silicon originally contained in the pig metal, and some of the sulphur, with a small part of the phosphorus, and the greater part of all other impurities. The carbon originally present has been oxidized, and has passed off by the chimney. In making "puddled steel," just as much carbon is left in the sponge as can be retained without depriving the metal of its power of welding. This is so small a quantity, however, that the metal might usually be better denominated iron.

The puddle-ball is as heterogeneous in its physical condition as in its chemical composition. It is irregularly porous, full of cavities of all sizes and shapes. The ductile metal is permeated with the brittle and non-coherent cinder in every part, and in all proportions. The skill of the puddler is displayed in reducing these defects, and in producing a puddle-ball of the greatest possible purity and homogeneousness of character.

Even with the greatest care, the workman finally takes from the furnace a mass of barely cohering metal, dripping with liquid cinder, and the object of succeeding processes is

to reduce this sponge to the form of homogeneous, strong, and ductile plate or bar.

No process yet known, except absolutely remelting, can free the metal entirely from the cinder, and it consequently happens that all common iron made from puddled metal contains enough cinder to give it a fibrous character. The best irons have, however, an exceedingly fine and uniform fibre.

Mill Work comprehends the several processes by which the puddle-ball is converted into finished bar or plate. The first operation, that of shingling, or of squeezing, has for its object the removal of the cinder from the ball while still molten. The ball is transferred directly from the puddling furnace to be squeezed by the squeezer, or to be shingled under the hammer, and there compressed until the liquid cinder is forced out, as water is squeezed from a sponge by the hand, and the ball is compacted into a dense billet or bloom of wrought, or malleable iron. It has then the form either of a parallelopiped, or of a cylinder, and is at once carried to the rolls. The rolling mill reduces the bloom by repeated operations to the shape of a plate, or a bar, and to the dimensions required.

In most cases, the "muck-bar," as it is called after its passage through the first or puddle-train of rolls, is cut and laid up in "piles" of convenient size, and, after reheating in the reheating furnace, is rerolled.

Repetition of this process improves the quality, and increases the uniformity of the product. The iron is called, after once reworking, "merchant bar," and, after a second operation, "best bar," and "wire iron," or refined bar. The muck-bar, or puddle-bar, is rough on its edges, coarsely granular in the fracture, and has slight tenacity, but considerable hardness. Merchant bar is of ordinarily good quality, smooth, ductile, fibrous, and strong, and the rerolled metal is of the finest quality, and should be able to bear the severest of the tests described in a subsequent article. This reheating and reworking improves the quality of the metal by securing greater homogeneousness, and by the

removal of a portion of the carbon and silicon left in the puddle-bar.

The best Yorkshire (English) irons are made by the method just described. The puddle-balls, however, are beaten under the hammer into flat masses, about one foot (0.3 metre) square, and 1½ to 2½ inches (3.8 to 6.3 centimetres) thick, and these are then broken up for inspection and assorted, the best made into the finer grades of iron, and those of less excellent quality worked into cheaper iron. The best grades are thus produced of uniformly fine quality.

The shape and dimensions of the piles, as built up to go into the reheating furnace, preparatory to being rolled into bars or plates, vary with the shape and size of the latter. In making merchant bar, the piles are of such form that they are lengthened from 20 to 60 times in the process of rolling, and their cross section correspondingly reduced. To secure uniformity in the character of the finished iron this proportion should be varied as uniformly as possible, from piles for large bars, in which the least reduction takes place, to those for small bars, in which the work done on the metal is greatest. To secure the least possible loss of strength in making large bars the proportion of work done in rolling, and the decrease of cross section of pile, should be the greater, if possible, with larger sizes of bar. The greater the amount of work expended on the bar, as a rule, in this reduction of section and in extension, the better the quality produced.

In making the better grades of iron rails, the piles are built up of puddle-bar, and made of a section 8 to 10 inches (20 to 25 centimetres) square, and capped, top and bottom, with slabs of iron of good quality, in order to secure good wearing power.

These piles are hammered, or rolled, or first hammered and then rolled, into a bloom, or billet, which is again heated, and finally carried to the rail-train and rolled into a rail.

The rail, when taken from the rolls, is cut to proper length, straightened, punched, properly marked, and sent to market. Piles for beams are similarly made and worked.

Piles for plate-iron are made more nearly square, and are comparatively thin and flat. For the best plate, slabs of selected puddled iron are piled together, and are usually welded under the hammer into conveniently shaped masses, preparatory to rolling. Special shapes, and some heavy pieces, as shafts for large steam-vessels, are "fagoted" and worked to shape under the hammer. The piles for such work are either made of rolled bar, or of scrap-metal of various shapes, sizes, and kinds. Carefully selected scrap makes excellent iron, as it has already been well worked.

The process of fagoting consists in binding a considerable number of bars into a pile or fagot, and these fagots are worked under the hammer like piles made in the way already described. Shafts are lengthened by piling or fagoting at the ends, and gradually building them out by additional fagoting as the mass is worked into shape under the hammer. Railroad axles are made both by rolling and by shaping under the hammer as just described. Tires and bands are often made by rolling. Very heavy plates, as the armor plates of ships, are usually made by welding together, in the rolls, several thinner plates. They are sometimes built up under the hammer. The size and thickness is only limited by the size and strength of the rolls of the furnace, and the machinery used in handling them.

Reheating is usually performed in a reverberatory furnace; melting pig metal for the purpose of charging rotary puddling furnaces is sometimes done in reverberatory furnaces, but usually in cupola furnaces—vertical furnaces cylindrical in form; in which the metal and fuel, with a small portion of flux, are charged as in blast furnaces, and from which the molten metal is drawn off at the bottom as required. Powerful blowing apparatus must be used to secure the needed air-supply.

Hammering.—The puddle-balls, when taken from the furnace, are compressed by either hammering or "squeezing" into blooms. At first, and frequently at the present time, heavy helve-hammers, Fig. 16, were used for this purpose. The hammer and its helve are usually of cast iron, although

the former is sometimes of oak or hickory. The weight resting on the anvil is from 5 to 8 tons (5,080 to 8,128 kilogrammes), the former being most frequently adopted. The hammer is raised by a revolving wheel with projecting wipers, or by a set of cams, which elevate the hammer to the necessary height, 15 to 20 inches (38 to 50 centimetres), and allow

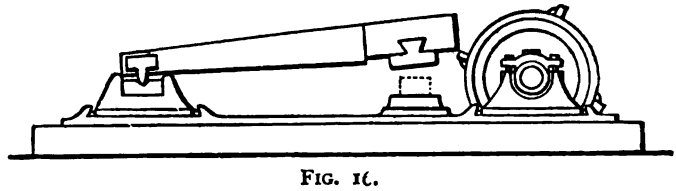


FIG. 16.

it to drop upon the puddle-ball. The rear end of the helve is carried by standards secured to a bed-plate, which extends under the anvil and cam-shaft bearings. The whole is mounted upon a foundation of timber and stone, or of timber alone, which frequently contains over 1,500 cubic feet (42.5 cubic metres) of oak. The whole structure weighs 30, or even 40 tons (30,480 to 40,064 kilogrammes), and covers a space of 20 to 25 by 6 to 8 feet (6 to 7 by 1.8 to 2.1 metres). The anvil block weighs 5 tons (5,080 kilogrammes) or more, the hammer itself nearly a ton (1,016 kilogrammes), and the helve several tons. The hammer makes from 50 to 75 blows per minute. When not in use, the end of the helve is caught at the extreme height of rise and supported by a prop.

When a puddle-ball is ready, it is laid on the anvil block and held by tongs in the hands of the hammer-man. The prop is knocked out, and the hammer, by a rapid succession of blows, works the ball into a bloom, the hammer-man meantime turning it from side to side, and sometimes presenting the end of the billet to the hammer. The bloom is taken from the anvil in a half minute, completely formed.

The steam-hammer, Fig. 17, in which the hammer is carried on the piston-rod of a steam engine, and rises and falls vertically, is now used to some extent. In that illustrated the piston-rod is very large, and the weight so great that no

"tup" is needed. The hammer-head is secured to the rod by a wedge-shaped ring, which is tightened up at every blow. The piston is welded to the rod. The valve-motion of the steam-hammer is usually made to work either automatically or by hand. That used for hammering puddle-balls is usually operated by hand.

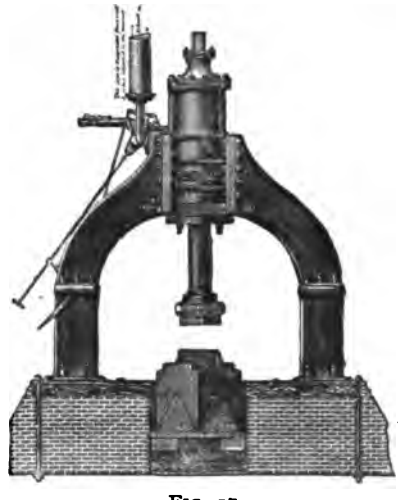


FIG. 17.

It is stated by iron makers that the impossibility of varying the intensity of the blow of the helve-hammer is an advantage not possessed by the steam-hammer. The expulsion of the fluid cinder from the puddle-ball is principally effected by the first heavy blows. With the steam-hammer, the operator may strike light blows at first, and work the ball into a bloom of which the weight will be increased, but the quality seriously reduced, by the presence of an excess of cinder.

The Squeezer is now oftener employed than the hammer in compressing the puddle-ball. The older form, Fig. 18, is known as the "alligator" squeezer. It consists of an anvil-block, upon which the puddle-ball is laid, as in hammering, and a vibrating jaw, which alternately presses down upon the puddle-ball and rises again to permit its manipulation by the workman. The jaw forms one end of a strong lever, pivoted near the working end, and operated by a crank-

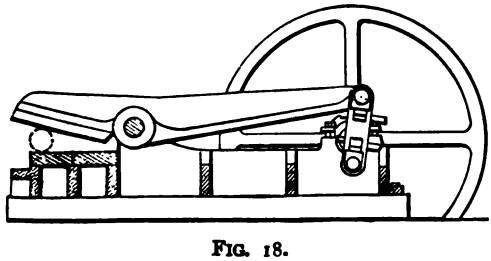


FIG. 18.

shaft and link, or connecting-rod, at the opposite extremity. There are sometimes two compressing parts, one on each side the axis on which the lever vibrates. The machine is often driven by connecting its crank-shaft to the puddle-train, or roughing rolls, by a connecting-spindle or coupling, such as is used for connecting the roll train to its driver.

The jaw and the anvil may be kept cool by the circulation of water through them in small lap-welded iron pipes cast in them.

The parts of the squeezer are subjected to immense stresses whenever the puddle-ball has, by accident or negligence, been permitted to get too cool. The resistance of white-hot iron to compression is very small, and, at a bright red heat, is only one-fourth that of cold iron; but the resistance increases with very great rapidity as the metal loses its heat. The squeezer is necessarily made very strong to meet such accidental strains. The length of life of the several parts is stated to be often but a month for crank-brasses, and of parts exposed to strain simply from three months to a year.

The Rotary, the Burden, or the Cam Squeezer, as it is variously called, is very generally used in the United States, and to a considerable extent in Europe.

This consists of a large cam mounted, sometimes on a vertical and sometimes on a horizontal, shaft, and revolving within a fixed cast-iron cylindrical casing. The puddle-ball is inserted at one side, at the moment when the space between the cam and the casing is widest at that point, and it is seized by the cam and rolled around within the casing, gradually assuming a cylindrical form as the space grows narrower, and finally issuing in the form of a billet ready for the rolls.

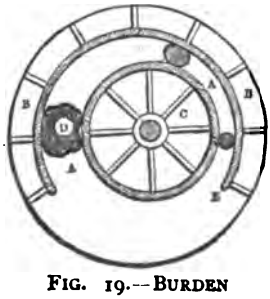


FIG. 19.—BURDEN SQUEEZER.

In another form the revolving shaft carries a cylinder instead of a cam, and the cylindrical casing is placed eccentrically to obtain a gradually diminishing space in which the billet is formed. This is the "Burden Squeezer." A

modification of the first of these forms has no casing, but the ball is compressed and formed between a vertical cam and a pair of rolls beneath it, on which rolls the puddle-ball is placed.

In some cases, the bloom is compressed lengthwise by the blows of a hammer while taking form in the squeezer. This gives a better and sounder bloom than can be obtained otherwise.

In still another form of squeezer, three pairs of rolls are used, one above another, the higher set being placed nearly on a level with the floor of the mill. The upper set are at such a distance apart that they will just seize the puddle-ball, and, compressing it somewhat, drop it between the intermediate rolls, which, in turn, deliver it still further compressed to the lower set, which turn out a finished bloom. The bloom drops from the third pair of rolls upon an apron, which raises it again to the floor of the mill.

Rolling Iron.—The puddle-ball is usually worked into a bloom five or six inches in diameter, and fifteen or eighteen inches long (12 to 15 by 38 to 45 centimetres), and is then taken to the rolling-mill.

These rolls are called the puddle-train or the roughing rolls, sometimes the breaking-down or the blooming rolls. In them the iron is first given the form of a bar, preparatory to being reheated and again subjected to the rolling process in the finishing train. The process of rolling was invented by Henry Cort, and at about the same time with his invention of the puddling process, the two inventions properly forming but details of one process. It was patented in 1784.

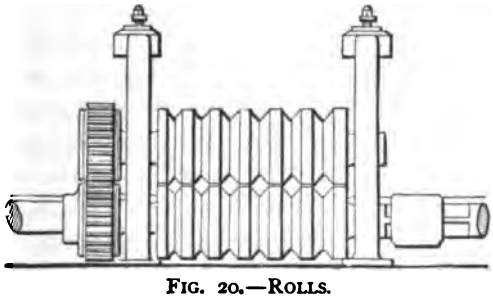


FIG. 20.—ROLLS.

The Common Form of Rolls, as adopted for both roughing and finishing, is shown in Fig. 20, in which

the roughing and a finishing train are shown as often driven together. These rolls, plain or grooved, are employed in making bars for the market, plate, flat bars for tram-rail and for beams, and for making wire rods. The finishing train for plates, beams, rails, and all kinds of heavy work, is gradually becoming superseded by either the "three-high" mill, or by the "reversing mill," to be hereafter described.

As usually made, the roll-train consists of pairs of heavy rolls so grooved that the bloom from the squeezer or the hammer may be readily entered at the first and largest grooves, where, passing through, it is reduced considerably in transverse dimensions and correspondingly extended, and can then be entered at the next groove, which is of smaller section. After passing through all the grooves in the roughing rolls, the slab or bar is sent to the next set or pair.

The first grooves in the first pair of rolls are often scored transversely, to insure their seizure of the bloom. The surfaces are hardened by casting the rolls in "chills."

The bloom, after each "pass," is lifted by the workman and sent back over the top roll to be entered again, and this is repeated until the mass has passed through all the grooves and is ready to enter the next set of rolls. This compression and change of form still further reduces the amount of slag in the iron. The operation results in the conversion of the rough bloom into a bar, which usually assumes a length of about 10 feet (3 metres), a breadth of 4 inches, and a depth of 1 inch (10 by 2½ centimetres).

The form of groove varies with the character of the work to be done. In the roughing rolls, as shown in the engraving, they are of such shape as to produce a bar of rectangular section. In the finishing rolls they are given a form which, in the first passes, is such as will take the bar or billet readily, and they change in form so as to gradually modify the section, finally delivering the bar in the form required. In small mills making light bar and wire iron, three rolls are used, one above the other, the middle roll turning in a direction opposite to the other two. In this case, the bar is entered on one side, between the lower and the middle rolls, and is returned between

the middle and the upper rolls, passing each way alternately, until it has gone through all the grooves, and finally emerges completely shaped.

The standards carrying the rolls are called "housings." The "body" of the roll is the portion between the housings. The "journals" are the portions within the housings, and support the rolls, while the ends, or "wabblers," project beyond the housings, and are seized and the rolls turned by the couplings and their connecting spindles. The bearings or "chucks" carrying the roll journals are capable of moving vertically in the housings. The lower box of the bearings of the lower roll is carried on the housing. The upper roll rides in bearings supported on the caps of the bearings of the lower roll, and is kept in position by the interposition of wedges between the two chucks, of which the lower is called the "carrier." Very strong screws, working through nuts in the top of the housings, bear upon the upper part of each box on the "riders" of the upper roll, and hold it down while the bar is passing through. The housings are supported by strong iron bed plates, to which they are bolted firmly. These plates are held down upon the foundation by heavy foundation bolts, and the foundation itself is deep and solid, and constructed of carefully laid masonry. The bed plates are sometimes made like a lathe bed, and the housings are thus rendered capable of lateral adjustment and of removal without inconvenience.

The connecting spindles are shafts of cast iron of such size that they will break under heavy strains more readily than the rolls, and from this fact they have been called "breaking spindles." The couplings which connect each end of the spindle to the roll, or driving shaft, are usually made weaker than the spindles. These pieces are fitted loosely to each other in order to permit considerable variation of position in the axes of the rolls without liability to breakage.

The rolls are made of a good and strong iron which will chill well. The housings are made of the very best and toughest iron, and the spindles and couplings of ordinary foundry iron.

"Rests" (pieces of wrought iron with edges of steel) are placed before the rolls and just below the level of the top of the lower roll upon which the bloom or bar is slid into the grooves, and "guides" are arranged on the opposite side to receive the bar and lead it from the rolls. Small roll-trains having guides on each side are called "guide-mills." Without these guides small bars or rods are liable to "collar," or, jamming in the grooves, wind about the roll. Heavy rolls for beams and rails are fitted also with side guides, to prevent lateral deviation. Wire brushes are also added, in some cases, to clean the issuing bars.

The Train is driven by a heavy shaft turned by the prime mover, which may be either a steam engine or a water wheel. A pair of gears, seen in the figure at the left of the train, and mounted in an independent pair of housings, connects the two lines of rolls. A line of water pipes is carried along the top of the train for the purpose of keeping the rolls and their bearings cool by a continually trickling stream.

The size of rolls varies with the character of their work. Heavy plate mills have rolls as large as 30 inches (76 centimetres) in diameter, and sometimes 8 feet (2.62 metres) or more in length. Twelve-inch and 8-inch (30 and 20 centimetres) trains are common sizes. Roughing rolls are 5 feet (1.5 metres) between housings, and 18 inches diameter.

The intermediate train, when one is used, and the finishing train, are carefully proportioned in general dimensions and in the graduation of the shapes and sizes of their grooves.

The rolls for plate mills are simply plain cylinders, and the thickness of the plate is determined by adjusting, at each pass, the screws which fix the position of the top roll. The wedges are usually replaced by counter-weighted levers, which hold the top roll in contact with the screw. The grooves, for ordinary symmetrical shapes, as "rounds and squares," are made alike in each roll, each groove representing one half of the section of the bar, and are held by screws in the housings in such a way as to prevent lateral movement.

In Rail and Beam Mills, collars project from the top roll, entering grooves in the bottom roll, and the space left between the collars and the bottom of the grooves is of the form and size required to shape the beam or the rail as it passes through in the groove. The larger parts of the bottom roll, separating the grooves, are called "collars," and that roll is known as the "collared roll." Similar rolls, having comparatively deep and narrow grooves and collars, are used for dividing flat iron into several small rods, and are called "slitting" rolls.

The velocity of the rolls varies with the character of the work, being greatest for light, and comparatively slow for heavy work. The extreme speeds for plate and bar mills are about 60 and 250 revolutions per minute respectively. Wire mills are driven very much faster.

The "Continuous Mill," invented by Bedson, consists of several sets of rolls, sometimes as many as sixteen, placed one in advance of the other, and each receiving the rod from its leader, and delivering it to its follower. It is used for rolling wire. A bar an inch (2½ centimetres) or more square, and 12 or 15 feet (3.6 or 4.5 metres) long, is heated throughout, and entered into the first pair of rolls. Passing from roll to roll, it is finally delivered as a long wire a quarter of an inch (0.6 centimetre) or less in diameter. The speeds are so adjusted that the rod is slightly drawn between each pair of rolls, and so that the rapidity of working is sufficient to keep up the temperature of the wire.

The "Universal Mill" is a form of mill in which the iron is acted upon in two directions, usually by horizontal and by vertical rollers, at each pass.

It was patented in 1853, and has received many modifications adapting it to special kinds of work. It is largely used for rolling beams, channel-bars, and girders.

As usually constructed, the universal mill consists of a pair of ordinary horizontal rolls, mounted in housings, and driven in the usual way, and of a pair of vertical rolls placed as close to the former as possible, and so mounted and driven that they can be moved toward or from each other.

The Rate of Cooling while the iron is passing through the rolls varies greatly with the temperature at its first pass, and with the magnitude and shape of the mass. The smaller the ratio of cubic to superficial dimensions, the more rapid is the loss of heat. Wire cools very suddenly; large beams and heavy shafting cool quite slowly. The wire issues from the train comparatively cool, while the larger pieces are still red hot when laid on the floor. The more rapid the compression and reduction of section, also, the more completely is the loss of temperature by conduction and radiation compensated by the generation of heat in the expenditure upon the metal of mechanical energy. A high speed of rolls is, in this respect, advantageous in making small bars and wire, and the number of passes is made as small as is possible without incurring liability to injury of rolls or of the bar by the squeezing of the metal outside the grooves, thus forming "fins," or of meeting with difficulty in entering the metal into succeeding grooves.

The hotter the iron the higher the velocity of the rolls, the greater their diameter and their strength, and the less marked the change in form of section, the greater is the amount of reduction allowable at each pass. Small rolls tend most to elongate, and large rolls to spread the metal.

The Product of the Rolling Mill is either bar iron, plate, or sheet iron, beams, girders, or peculiar shapes made for special kinds of work.

The quality of the product of the rolling mill depends upon the original quality of the metal, upon the care taken in rolling, and upon the cleanliness of surfaces which are welded together in the process.

This will be considered at length when treating of iron as a material of construction.

The manager of the rolling mill endeavors to see that the puddling is efficiently performed, that the puddle-ball is made up as free as possible from cinder, that the cinder in the ball when taken from the puddling furnace is worked out as completely as possible under the hammer, or in the squeezers, that the iron is carried through the roughing-rolls while still at a proper temperature, that the reheating and

subsequent rolling is done at a good heat, that all surfaces are perfectly clean where they are to come in contact and to be welded together, and that cinder and scales of oxide are not allowed to collect on the metal or on the rolls, where they may produce roughness or depression in the finished surface of the iron.

A complete and rigid system of inspection and individual responsibility for work done should be instituted and kept up in every mill.

Forms of Wrought Iron.—The forms of wrought iron met with in market may be divided into six general classes, viz.:

1st. *Bar iron*, whose forms, round, square, and flat, are so generally known as to render little further description necessary.

Bars are usually known as either round, square, octagonal, or flat, according to the shape of their cross-section, and the former are rolled from less than one-quarter up to six inches in diameter. Except for shafting and chain cables, a greater diameter than 1½ inches is seldom called for. Beams are seldom larger than 15 inches in depth, and are given an I-shaped section. Sheet iron is now used—boiler plate—as thick as 1¼ inches (3.2 centimetres), but the most common sizes are ¼, $\frac{5}{16}$, and ⅜ inches thick (0.63, 0.78, and 0.95 centimetre). Their breadth is usually from 2 to 4 feet (0.61 to 1.22 metres), and length such as will not make them too heavy to be handled by three or four men. Armor plate has been rolled 26 inches (66 centimetres) in thickness.

2d. *Special forms* of bars, including:

Angle iron, having a section like the letter L; it is rolled into lengths similar to bar iron (Fig. 30).

T-iron having a section like the letter T (Fig. 21).

FIG. 21.

FIG. 22.

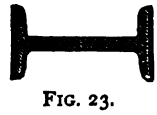


FIG. 23.

Channel iron (Fig. 22).

Beam iron (Fig. 23).

Half-round iron (Fig. 24).

FIG. 24. FIG. 25. FIG. 26. FIG. 27. FIG. 28. FIG. 29.

Bulb iron (Fig. 25).

Feathered iron (Fig. 26.)

These several forms are designed to meet special require ments in bridge, house, or ship construction.

3d. *Rails.* The shapes now in use are:

Bridge rail (Fig. 27).

Flat-bottomed or T-rail (Fig. 28).

Double-headed rail (Fig. 29).

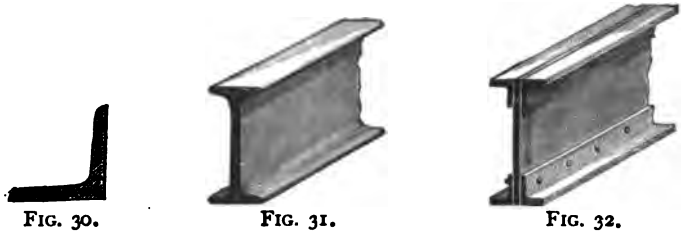


FIG. 30. FIG. 31. FIG. 32.

The flat-bottomed rail is the one in common use in this country.

4th. *Beams and girders*, either solid, as Fig. 31, or built up, as in Fig. 32.

5th. *Sheet iron*, of all shapes and sizes.

Special forms, not standard, can usually be obtained from the mill; but these, as well as odd sizes and irregular shapes, are charged for as extras.

The boiler-plate manufacturers have settled upon the nomenclature of plate-boiler thus:

(1st.) On and after January 15, 1881, the letters *C. No.* 1 are to be dropped in stamping plate iron, and the word *Refined* be substituted therefor.

(2d.) On and after January 15, 1881, the letters *C. H. No.* 1

and *C. H. No.* 1 *Shell*, before used in stamping plate iron, are to be dropped, and the word *Shell* substituted therefor.

No change was made in the designation of flange iron, which remains "C. H. No. 1 Flange."

Originally, the best boiler plate for shells was stamped "C. No. 1," *i. e.*, "Charcoal No. 1," and the next grade "C. No. 2." Manufacturers of plates for marine boilers were, however, required to stamp the grade called for as a standard by the Navy Department, "C. H. No. 1," *i. e.*, "Charcoal Hammered No. 1." From that time the "C. No. 1" brand has been used for the second grade. But the same grade from different mills is not always of the same quality.

To get reliable boiler iron, the purchaser will buy plates bearing the private stamp of a reliable mill as well as the grade.

The old designations are still very generally retained, however, in the trade. Of these, "C. No. 1," Charcoal No. 1, is quite a hard iron, which does not flange well, and is used in boiler shells, and wherever it is not to be subjected to great changes of shape; its tenacity is usually about 40,000 or 45,000 pounds per square inch (2,812 to 3,295 kilogs. per sq. cm.). "C. No. 1 R. H." is a better grade, and makes a durable fire-box iron, but cannot usually be well flanged.

"C. H. No. 1 S." is sold especially for boiler shells and similar purposes; it is still stronger than the preceding; it is unfit for flanging. The tenacity of this iron ranges from 50,000 to 55,000 pounds per square inch (3,515 to 3,767 kilogs. per sq. cm.) tested lengthwise the sheet and about three-fourths this strength in the other direction. "C. H. No. 1 F.," Charcoal Hammered No. 1 Flange Iron, is of about equal strength with C. H. No. 1 S., but is more thoroughly refined, and is soft, ductile, and tough enough to flange well; its superior homogeneousness gives it nearly equal tenacity in both directions. "C. H. No. 1 F. B.," Charcoal Hammered No. 1, Fire-box Iron, is a harder and rather stronger iron, which may also be flanged. "C. H. No. 1 F. F. B.," Charcoal Hammered No. 1 Flange, Fire-box Iron, is a still better grade.

Single refined iron is that produced by cutting up the "muck bars" obtained by rolling the puddle-ball, piling, heating, and re-rolling it to size.

Double refined iron is that which is made by repeating the latter process, and rolling to size.

Good "double refined iron" is usually expected to have a tenacity in large pieces, as in bridge rods, of at least 50,000 pounds per square inch (3,515 kilogs. per sq. cm.), and an elastic limit, as generally measured, of 26,000 to 30,000 (1,848 to 2,109 kilogs. to the sq. cm.). It should bend double over a bar of its own diameter.

Compression members of structures are usually made of "single refined iron." Tension members are expected to be of better grade, and are made of "double refined iron."

6th. *Wire.*

Wire-Drawing.—As small rods cannot usually be reduced to the sizes distinctively classed as wire in the rolling mill, wire is generally produced by the process known as *wire-drawing*. The larger sizes above ⅛ inch (0.32 centimetre) diameter are, however, often rolled, and especially where the iron is of too poor quality to permit it to "draw."

The Draw-Plates, or Die-Plates, are blocks of cast-steel perforated with conical holes carefully gauged, the smallest diameter of each being that of the wire to be drawn from it. These holes are frequently gauged by the workman, and, when worn, the metal is hammered around the small end of the hole to close it up, and then carefully reamed out to size again. The taper of these holes is best made slight, as in Fig. 33.

FIG. 33.

The wire-blocks, or wire-drawing machines, consist of a substantial bench on which is mounted a strong cast-iron drum, ordinarily about 2 feet in diameter for No. 10 (0.13 inch, 0.33 centimetre) wire, on which the wire winds as it is drawn through the plate. This drum is turned by a vertical spindle 2 inches in diameter, on which it is mounted, square projections on a cam mounted on the spindle entering recesses of similar form in the disk which forms the bottom of the drum. This cam or cross-head which drives the drum is carried by a square por-

tion of the spindle which passes through a hole in the cam. When the drum is raised far enough to clear the projections which drive it, it turns freely on the spindle, and can be rotated either forward or backward. A set of levers keeps the drum in any desired position, either engaged with the driving lugs or above them, where it may be conveniently turned or stopped at will. These levers are worked by the foot. In a later and better machine the drum is driven by a friction-cone instead of by a clutch.

The vertical spindle is driven by a horizontal shaft and bevel gearing, and the latter shaft by pulleys belted from the line-shafting.

The draw-plate is mounted on the bench in a frame strongly bolted down to the table.

The coil of wire to be drawn is mounted on a reel conveniently placed, and the end of the point, tapered sufciently, is carried through the plate and seized by "nippers" or "grippers" attached to the driving cam.

The spindle being set in motion, the wire is drawn through the die-plate far enough to permit of its being securely clamped to the drum. It is then released from the nippers and made fast to the drum, which is then set in motion, and the coil is drawn through the plate, winding on the drum as it issues, and is now one size, and sometimes two sizes, smaller than before.

The moment of resistance in drawing No. 10 to No. 11 (0.134 inch to 0.12 inch, 0.34 to 0.3 centimetre), as given by experiments made for the Author, is about 350 foot-pounds (48.3 kilogrammetres); the velocity of the wire is about 250 feet (76 metres) per minute. Larger wire is drawn on drums of 1 or 2 inches (2½ to 5 centimetres) greater diameter and at lower speeds, reaching a minimum of 150 feet (45.6 metres) per minute. Smaller sizes are drawn on drums of 22 inch (56 centimetres) or less diameter, and at speeds running up to 500 feet (152 metres) per minute.

The Resistance offered by Wire in passing through the draw-plate varies with the size of wire, character of metal, and arrangement, proportions, and management of the wire-

blocks. Good metal, under ordinarily good conditions, requires, to reduce it one size, from 100 pounds (45.4 kilogrammes) with the finer, to 1,000 pounds (454 kilogrammes) of the larger grades. The ratio of reduction of area of section is usually about 1⅓ to 1.

An approximate value for good wire is obtained by the empirical equation

$$P = \frac{30}{0.250 - d};$$

in metric measures,

$$P_m = \frac{14}{0.25 - 0.4d_m},$$

in which P is the pull and d is the diameter of the wire.

The velocity of drawing is, customarily, in feet per minute, nearly

$$V = 25N,$$

where N is the number of the wire on the Birmingham gauge.

The power demanded is, therefore, at the draw plate, in British measures,

$$\frac{PV}{33{,}000} = \frac{750N}{33{,}000(0.250 - d)}.$$

In drawing down billets, the heaviest work and greatest reduction of size take place in the "roughing" or "nipping" blocks, and no special attention is paid to the size or to gauging. The last drawing is done in the "finishing blocks," and the wire is carefully drawn precisely to gauge.

In "wet-drawing" the metal is drawn directly from the lees-tub in which it receives the alkaline coating, and the wire is thus preserved from oxidation, as is also the draw-plate, and is, at the same time, lubricated. Lime-

coated wire is drawn through grease. Bright wire is drawn dry.

Wire is often "coppered" by drawing it through a bath of solution of copper sulphate, or is tinned or "galvanized" by leading it through a bath of tin or of zinc kept at a temperature slightly above the melting point, to the finishing block.

When finished, sizes 0 to 20 are made up into "bundles" weighing 63 lbs. (28.6 kilos) each, and smaller sizes into "stones" of 12 lbs. (5.4 kilos) each. The smallest size ordinarily met with is No. 36 (0.004 inch, 0.102 centimetre diameter), but No. 40 (0.003 inch, 0.008 centimetre diameter) has been made.

Sizes.—Wire is gauged by the "Birmingham Wire Gauge" in Great Britain, and by the "American Gauge" sometimes, but not usually, in the United States. The table on page 124 gives the sizes of the standard numbers.

The Processes of Rolling and of **Wire-Drawing,** greatly increase the strength of iron. Good iron, which, in round bars, 2 inches (5.08 centimetres) in diameter, has a tenacity of 54,000 pounds (3,780 kilogrammes per square centimetre) per square inch, when rolled into one inch rods often attains a strength of 60,000 pounds (4,200 kilogrammes). When drawn into No. 10 wire (0.134 in., 0.34 centimetre), its strength becomes about 90,000 (6,300 kilogrammes), and Nos. 15 and 20 (0.072 and 0.035 in., 1.8288 and 0.88899 millimetres), respectively, have a tenacity of about 100,000 and 111,000 pounds per square inch (7,030 and 7,733 kilogrammes per square centimetre). A wire ⅛ inch (0.31 centimetre) in diameter is ordinarily expected to sustain 1,000 pounds (454 kilogrammes), and one of $\frac{1}{32}$ inch (0.079 centimetre) diameter, should carry 100 pounds (45.4 kilogrammes).

In wire mills, great skill and judgment are necessary in choosing good metal, and in preserving its excellent qualities throughout the processes of reduction in the rolling mill and in drawing.

Good iron for fine wire must be pure, free from cinder, strong and ductile, and probably must have a comparatively

GAUGE OF WIRE.

NUMBER OF GAUGE.	DIAMETER, BIRMINGHAM GAUGE.		DIAMETER, AMERICAN GAUGE.	
	INCH.	MILLIMETRES.	INCH.	MILLIMETRES.
0000	.454	11.532	.46	11.684
000	.425	10.795	.40694	10.336
00	.38	9.6519	.3648	9.266
0	.34	8.6359	.32486	8.2511
1	.3	7.6199	.2893	7.3481
2	.284	7.2135	.25763	6.5437
3	.259	6.5785	.22942	5.8272
4	.238	6.0451	.20431	5.1894
5	.22	5.588	.18194	4.6212
6	.203	5.1562	.16202	4.1153
7	.18	4.572	.14428	3.6647
8	.165	4.191	.12849	3.2636
9	.148	3.7592	.11443	2.9065
10	.134	3.4036	.10189	2.588
11	.12	3.048	.090742	2.3048
12	.109	2.7686	.080808	2.0525
13	.095	2.413	.071961	1.8278
14	.083	2.1082	.064084	1.6277
15	.072	1.8288	.057068	1.4495
16	.065	1.651	.05082	1.2908
17	.058	1.4732	.045257	1.1495
18	.049	1.2446	.040305	1.0237
19	.042	1.0668	.03589	.9116
20	.035	.88899	.031961	.8118
21	.032	.81279	.028462	.7229
22	.028	.71119	.025347	.64381
23	.025	.63646	.022571	.5733
24	.022	.55879	.0201	.51054
25	.02	.508	.0179	.45466
26	.018	.4572	.01594	.40487
27	.016	.4064	.014195	.36055
28	.014	.3556	.012641	.32108
29	.013	.33096	.011257	.28593
30	.012	.3048	.010025	.25463
31	.01	.254	.008928	.22677
32	.009	.2286	.00795	.20193
33	.008	.2032	.00708	.17983
34	.007	.1778	.006304	.16012
35	.005	.127	.000614	.14259
36	.004	.1016	.005	.127
37	....	.....	.004453	.11311
38	....	.....	.003965	.10071
39	....	.....	.003531	.08969
40	....	.....	.003144	.07986

low elastic limit. It has been observed, that of two irons selected, both having great strength and ductility, that which stood lowest in *both* respects would draw into the finest wire. The only peculiarity detected by the Author, in this case, was a comparatively low elastic limit, as shown on the automatically produced strain-diagram.

Charcoal-bloom iron is usually found best adapted for wire-drawing if free from cinder and coal.

Very excellent metal has been made by the Bessemer and Siemens-Martin process for wire of sizes exceeding No. 10.

Irregular and Peculiar Shapes, which cannot be produced in the rolling mill, are given to wrought iron by the process of forging. This constitutes a trade, the methods and principles of which are properly the subject of a special treatise.

The art consists principally in working simple forms, as bar or plate iron, into more complicated shapes, by hammering at a bright red heat, and in making up larger masses and forming them as desired, by welding together smaller pieces. This work is sometimes done by the common hammer and sledge, and on the anvil and in formers by the blacksmith, sometimes under the steam or trip-hammer, or under the drop-press. It is also sometimes done under the hydraulic press. The practice of special methods, and the use of special tools for peculiar forms and sizes, is an important branch of the art. The conditions of success in doing this class of work are: the choice of iron free from sulphur and phosphorus, but containing some silicon where it is to be welded; working at a bright red heat, and welding at a white heat, or "welding-heat," with thorough fluxing; working rapidly, and with the least possible number of heats; and keeping the direction of "grain" as nearly as possible in the line of strain anticipated, and without breaking the fibre.

Irregular shapes and peculiar forms are made in cast iron by the processes of *moulding and founding*, which must also be described in detail in special treatises on that trade, on designing work to be made in cast iron, and on pattern-making.

The method, briefly described, consists in the preparation of a pattern, or mould, usually of wood, but sometimes of plaster or of metal—of the shape of the piece to be made, modified in some respects to avoid difficulties arising in moulding.

This pattern is imbedded in moulding sand, and, when removed, leaves an impression which has the shape of the casting which is to be made. Molten metal, poured into the mould thus made, solidifies in the desired shape. Cavities in the casting are produced, sometimes, by making similar cavities in the pattern, and moulding within them masses of sand, which displace metal in the mould so as to produce the proper form of cavity in the casting. Oftener, however, a projection is made on the exterior of the pattern, which corresponds in location and in its cross-section with the mouth of the opening desired. These "core-prints" leave in the mould impressions, into which the "cores" fit, and by which the latter are firmly held. The cores are masses of sand, which have been moulded in "core-boxes," and given precisely the shape of the cavity, but with extensions at those points at which the cavity comes to the exterior surface of the castings. These extensions fit into the impressions made by the core-prints, and the core is thus held in place while the molten metal is flowing around it.

The Work of Designing metal parts of machinery involves the intelligent consideration of the cheapest and most satisfactory methods of moulding those which are to be cast, as well as of forging parts made of wrought iron and steel. The pattern-maker must also know how to prepare the pattern, so as to avoid the difficulties frequently met with in moulding.

The moulder is required to know how to mould the piece in order to secure sound castings; and the founder must understand the mixing and melting of metals in such a manner as will give castings of the required quality. The engineer should know what forms can be cheaply made in cast metal, and what cannot be cast without difficulty, or without liability to come from the mould unsound. He should be

able to instruct the pattern-maker in regard to the form to be given the pattern in order to make the moulder's work easy and satisfactory, to tell the moulder how to mould the pattern, with what to fill his flask, and how to introduce the molten metal, and to provide for the escape of air, gas, and vapor, and he should be able to specify to the founder the brands and mixtures of iron to be chosen.

Malleableized Cast Iron, or malleable cast iron and steel castings, are castings made originally of ordinary cast iron, which have been subjected to a process of decarbonization which results in the production of a crude wrought iron. The process is conveniently applicable only to small castings, although pieces of considerable size are sometimes thus treated. Handles, latches, and other similar articles, cheap harness mountings, ploughshares, iron handles for tools, wheels and pinions, and many small parts of machinery are made of malleable cast iron, or as steel castings.

For such pieces, charcoal cast iron of the best quality should be selected in order to insure the greatest possible purity in the malleable product.

The castings are made in the usual way, and are then imbedded in oxide of iron—in the form, usually, of hematite ore—or in peroxide of manganese, and exposed to the temperature of a full red heat for a sufficient length of time to insure the nearly complete removal of the carbon. The process, with large pieces, requires many days.

If the iron is carefully selected, and the decarbonization is thoroughly performed, the castings are nearly as strong, and sometimes hardly less malleable, than fairly good wrought iron, and they can be worked like that metal. They will not weld, however.

The pig-iron should be very free from sulphur and phosphorus. The best makers have usually melted the metal in crucibles having a capacity of 50 to 75 pounds (22 to 34 kilogrammes), keeping it carefully covered to exclude cinder and other foreign matter.

The furnace is similar to that of the brass foundry, from 2 to 2½ feet (0.6 to 0.75 metre) square, and the fire is kept up

by natural draught. The temperature is determined with sufficient accuracy for the practical purposes of the founder by withdrawing a portion on an iron bar. If hot enough, the drop burns on exposure to the air. If right, the metal is poured quickly.

The "cementation," or decarbonization, is conducted in cast-iron boxes, in which the articles, if small, are packed in alternate layers with the decarbonizing material. As a maximum, about 800 or 1,000 pounds of castings are treated at once. The largest pieces require the longest time. The fire is quickly raised to the maximum temperature, but at the close of the process the furnace is cooled very slowly. The operation requires from three to five days with ordinary small castings, and may take some weeks for large pieces. This process was invented in 1759.

Decarbonization is often performed, in the production of steel castings, by a process of dilution accompanied with, possibly, some "dissociation." By the preceding method the carbon takes oxygen from the surrounding oxides, and passes off as carbon monoxide (carbonic oxide); in the process now referred to the carbon of the cast iron is shared between the latter and the wrought iron mixed with it in the melting pot, and a small portion may possibly pass off oxidized. The latter method has been practiced to some extent for a century.

Selected cast iron and good wrought iron are melted down together in the crucible and cast in moulds like cast iron. The metal thus produced contains a percentage of carbon, which is determined by the proportions of cast and wrought iron in the mixture. The amount is so small, frequently, that the castings made can be forged like wrought iron. The process is properly a steel-making process, and will be considered at greater length when treating of the manufacture of steel.

Tin-Plate is sheet iron coated on both sides with a very thin layer of tin. The market is supplied with two kinds: charcoal plate, and coke plate.

The blooms intended for manufacture into tin-plate are

prepared in Wales, whence the greater part of the tin-plate in the market is received, by refining with charcoal and reworking after reheating in a coke fire.

The metal selected is usually perceptibly red-short, the effect of sulphur, although deleterious at a high temperature, being to confer upon the metal exceptional toughness when cold.

The pig-iron loses about 25 per cent. of weight in refining and conversion into bar. The bar is usually about 30 feet (9.1 metres) long, 6 inches (15.2 centimetres) wide, and 1½ or 1¾ inches (3.8 to 4.4 centimetres) thick.

The bars are cut up into pieces a foot long, piled, reheated, and rolled into finished bars, losing again about 25 per cent. in weight, and taking about ⅝ or ¾ ton (635 to 762 kilogrammes) of coke per ton (1,016 kilogs). The short finished bars are given such size and proportions as best fit them to be worked into plate of the thickness and other dimensions proposed. The bars, cut to proper length, are taken to the rolling mill, where they are reheated in a reverberatory furnace, rolled, doubled, and reheated, and again rolled, the rolling being repeated from four to six times, and the bar gradually assumes the form of a small, rectangular sheet, which, after being sheared to gauge, is ready for the operations preparatory to tinning. In rolling the bar, it is passed through the rolls with its axis parallel to that of the roll. Throughout these processes the greatest care is taken to keep the metal, when heating it, under a deoxidizing flame, and to avoid every cause of injury of surface, as by the formation of scales.

The pile of plates, brought finally from the rolls, is "opened," the sheets separated, each bar having made, usually, eight or sixteen sheets. The more frequently they are doubled, the greater the waste in rolling.

The plates are next "pickled," in a bath of dilute sulphuric or hydrochloric acid in leaden vessels heated by a fire beneath, are then washed thoroughly two or three times, and finally dried and annealed by heating in tight boxes to a bright red heat, and slowly cooled.

The annealed plates are "cold rolled" between very

smooth and accurately turned rolls, again annealed at a moderate temperature, and pickled and washed again. Those which are not well cleaned and smooth are scoured with fine sand, and all are singly examined and are handed to the tinner as nearly as possible absolutely clean.

The Tinning is done by a "gang" consisting of the "tinman," the "wash-man," the "grease-boy," and the "list-boy." The first receives and inspects the plates and places them in a trough of clean water, whence they are taken as required and immersed in a vessel containing warm melted grease. When well coated with grease they are put into the "tin-pot" and submerged in molten tin, the surface of which is flooded with grease, and kept clean by plunging into it wooden sticks, the gas and vapor evolved from which carry impurities to the surface, and check oxidation. This tinning is repeated in the "wash-pot," which contains tin of better grade, and at a lower temperature, and the plates are again carefully brushed and cleaned, and, finally, are dipped into another compartment of the wash-pot, in which they take a coating of the best quality of tin. The plates are then removed to the "grease-pot," in which, under grease, a small quantity of tin is kept at a temperature exceeding the melting-point, the superfluous metal is drained off the plates. On removal, they are cooled in the "cold pot."

The "list pot" contains molten tin in a pool at the bottom, only about a quarter of an inch deep. The line of tin of excessive thickness, which forms at the lower edge of the plate when draining and cooling, is here melted off, and the plates are scoured with bran and woolen cloths, and are ready for inspection, classification, and packing for market.

A Box of "IC" plates contains 225 sheets, each 13¾x10 inches, and, if standard, weighs 112 pounds. If not less than 109, nor more than 115, the box would pass in the market. A box of "HC" tin weighs 119 pounds; one of "IX" weighs 140; one of "IXXXXXX" weighs 245. "D" plates are packed 100 in a box, are 16¾x12½, and weigh from "DC," 98, to "DXXXX," 189 pounds.

In making coke plates, the cast iron is refined, and is

usually puddled instead of being decarbonized in the refinery. The loss of metal is about the same.

"*Terne-plates*" are tinned with an "alloy" of tin and lead; the proportion of tin varies from one-third to two-thirds. These plates are largely used for roofing.

Russian Sheet-Iron is a thin sheet iron used for purposes requiring a smooth polished surface, which is not likely to oxidize readily, as for stove-pipe. The bright surface coating consists of iron oxide. It is made of a fine quality of wrought iron, rolled and annealed. The polish is given by hammering packages of the sheets with charcoal interposed. The best is imported from Russia; but less excellent iron of this class is made in other countries.

In Russian works, selected iron is hammered into slabs of the right size to make each a finished sheet. The slab is passed through the rolls three or four times, and subsequently hammered again. Several sheets are then heated to a full red heat, covered with charcoal shaken on them from a bag made of coarse linen, and piled with covering sheets of heavier iron, top and bottom. The pile is then worked down under a heavy hammer, nearly to the finished size. When cool, the hammering ceases, the plates are separated, reheated, and piled again with cold plates interposed, the hot and cold sheets alternating in the pile, and hammering them until cool, they are finished. They are then separated, cut to size, weighed and assorted for the market. The loss of metal in the manufacture is sometimes 30 per cent.

The sheets are usually about 5 feet by 2½ (1.6 by 0.8 metres) in size, and weigh from 6 to 12 pounds (2.7 to 5.4 kilogs), exceptionally heavy plates being made, however, weighing 30 pounds (13.6 kilogs).

The rolls make 75 or 80 revolutions per minute, and require driving power of about 40 horse-power. The hammers have very broad faces.

The finished sheets should be capable of being bent from four to six times without cracking.

CHAPTER V.

THE MANUFACTURE OF STEEL.

Steel is variously defined by acknowledged authorities, and the metals known in the market and to the trade as steel cannot be completely and satisfactorily classed under any definitions yet proposed.

The term includes, as formerly accepted, all impure irons which, in consequence of the presence of other elements, have the property of hardening by sudden cooling from a high temperature, and of taking a definite "temper," or degree of hardness, by a definite modification of temperature, and which may also be forged.

It has been more recently proposed to define steel as a compound consisting principally of iron, which has been rendered homogeneous by fusion; still another definition is "iron recarbonized." The first definition is based upon composition and properties; the others upon the method of manufacture. The latter compels the engineer to ascertain the history of the metal before he can give it a name. The trade has practically adopted the last method of nomenclature.

An international committee, appointed at the instance of the American Institute of Mining Engineers, in the year 1876, recommended the following nomenclature:

I. That all malleable compounds of iron with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any forms of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called "wrought iron," shall be called WELD-IRON (German, *Schweisseisen;* French, *fer soudé*).

II. That such compounds, when they will, from any cause, harden and temper, and which resemble what is now called

"puddled-steel," shall be called WELD-STEEL (German, *Schweiss-stahl;* French, *acier soudé*).

III. That all compounds of iron with its ordinary ingredients, which have been cast from a fluid state into malleable masses, and which will not sensibly harden by being quenched in water, while at a red heat, shall be called INGOT-IRON (German, *Flusseisen;* French, *fer fondu*).

IV. That all such compounds, when they will from any cause so harden, shall be called INGOT-STEEL (German, *Fluss-stahl;* French, *acier fondu*).

As arranged by Wedding, the following is the scheme of the system:

- Iron.
  - Forgeable; difficult to melt: — Forgeable iron — I.
    - Obtained in a fluid state:
      - A. Ingot iron.
        - Hardening: 1. Ingot steel.
        - Not hardening: 2. Ingot iron.
      - Obtained in a non-fluid state:
        - B. Weld iron.
          - Hardening: 3. Weld steel.
          - Not hardening: 4. Weld iron.
  - Not forgeable; easy to melt: Pig iron. — II.
    - With amorphic carbon only: C. White pig.
    - With graphite: D. Gray pig.

There may be added, called as formerly, *Remelted* pig iron—cast iron; *remelted* steel of every description—cast steel. Here the division following the fluid or non-fluid state keeps the principal place; the hardening only the second.

The grades are practically distinguished quite readily, thus:

I. and II. by their capability of being readily forged, or otherwise; A and B by their characteristic fracture; C and D by their color. Or, by chemical analysis, according to Wedding, the percentage of carbon will be:

- Iron.
  - I. contains from 0.0 to 0.3 per cent.
  - 2 and 4 contain from 0 to 0.6 per cent.
  - II. contains 2 to 3½ per cent.
- Steel.
  - 1 from 0.6 to 3 per cent. C.
  - 3 from 0.6 to 3 per cent. C.

The higher figure for steel is unusually large.

The American Institute of Mining Engineers, discussing the report of the International Committee on Nomenclature,

assented to the following as a correct *Commercial Nomenclature* of iron and steel, while recommending the use of the proposed nomenclature in papers written by members.

- Iron.
  - Wrought.
    - Bloom.... Catalan; Finery.
    - Puddled.. Bars; Plates; Beams, etc.
    - Steel..... Blister; German; Shear; Puddled.
  - Cast.....
    - Not malleable.... Pig iron; All ordinary castings.
    - Malleable. Castings, annealed and decarbonized in oxides.
      - Steel.
        - Castings not highly carbonized. Crucible.
        - Bessemer, or pneumatic.
        - Open hearth.. Siemens-Martin; Siemens by pig iron and ore process.

The metals called Steel grade into each other by imperceptible variations. Hand-puddled iron has the properties of crucible steel and ingot metals, which are considered by the trade as indisputably steel; while the product of the Bessemer and other processes yielding ingot metal is, when containing very little carbon, sometimes as fibrous and silky in texture as common wrought iron.

Steel, made at one of the largest works in France, is classified into three divisions, A, B, and C; of which A covers all cheaper grades of steel, such as are produced by the Bessemer and the Siemens-Martin processes, and the low grade crucible steels; division B includes steels of ordinarily good quality; and C includes the purest and best metals, such as are made from the best Dannemara, or similar Swedish ores, from charcoal pig and by the crucible process.

Each division thus designated by the purity of the metal is subdivided, according to "temper" or hardness, and the several grades of temper are determined by mechanical test

These grades are selected by the eye, all ingots being "topped"—*i. e.*, having the top broken off—before being rolled, inspected, and assorted into these grades.

Although the proportion of carbon mainly determines the grade or temper of a steel, other elements frequently, and sometimes greatly, modify its quality. Silicon, manganese, chromium, sulphur, and phosphorus, are the most common of these modifying ingredients. Steels made by alloying iron with tungsten, chromium, and titanium, are sometimes called "compound" steels.

The distinction which is often made between irons and steels according to method of manufacture, and which classes metal made by any process involving welding, and metal made by melting and casting into ingots as steel, is sometimes made the basis of a double classification of steels, thus:

CARBON, PER CENT.	WELDED METAL. ("IRONS.")	CAST METAL. ("STEELS.")
0 to 0.25	Common iron.	Very soft steel. "Homogeneous metal."
0.15 to 0.45	Granular iron.	Soft steel.
0.45 to 0.55	Steely iron; puddled steel.	Semi-soft steel.
0.55 to 1.50	Cemented iron or steel.	Hard steel. Tool steel.

One of the largest makers of Europe divides all steel into four classes:

1st Class.—Extra mild steels. Carbon, 0.05 to 0.20 per cent. Tensile strength, 25 to 32 tons per square inch. Extension, 20 to 27 per cent. in 8 inches of length. These steels weld and do not temper. Used for boiler-plates, ship-plates, girder-plates, nails, wire, etc.

2d Class.—Mild steel. Carbon, 0.20 to 0.35 per cent. Tensile strength, 32 to 38 tons per square inch. Extension, 15 to 20 per cent. Scarcely weldable, and hardens a little. Used for railway axles, tires, rails, guns, and other pieces exposed to heavy strains.

3d Class.—Hard steel. Carbon, 0.35 to 0.50 per cent.

Tensile strength, 38 to 46 tons per square inch. Extension, 15 to 20 per cent. Do not weld, but may be tempered. Used for rails, special tires, springs, guide-bars of steam-engines, pieces subject to friction, spindles, hammers, pumpers.

4th Class.—Extra hard steel. Carbon, 0.50 to 0.65 per cent. Tensile strength, 46 to 51 tons per square inch. Extension, 5 to 10 per cent. Do not weld, but may be strongly tempered. Used for delicate springs, files, saws, and various cutting tools.

The peculiarities and the characteristics of the several grades of carbon steels, and the differences produced by the introduction of the various metallic and non-metallic elements found in manufactured steels, and the modification of quality produced by special treatment, will be described at length in a chapter on the properties of steel.

The International Committee's classification may be put in the following convenient form:

I. CANNOT HARDEN—IRON.			II. CAN HARDEN—STEEL.	
Puddled iron. *Bloomary iron.* *Malleable castings.*	A, has not been fused—*weld iron.*	Weld Metal.	A, has not been fused — *weld steel.*	*Blister steel.* *Puddled steel.* *Shear steel.*
Bessemer iron. *Siemens-Martin iron.* *Crucible iron.*	B, has been fused—*ingot iron.*	Ingot Metal.	B, has been fused — *ingot steel.*	*Bessemer steel.* *Siemens-Martin steel.* *Crucible steel.*

The Steel-Making Processes may be divided into three classes: (1.) That which includes those steels made of malleable or wrought iron carburetted; (2.) That which comprehends all processes in which metal rich in carbon, as common cast iron, is partially decarbonized; (3.) That in which highly carburetted iron is first completely decarbonized and then recarbonized to the proper degree in a single process.

The common "Crucible Process" is of the first class; one form of the pneumatic process, and the ordinary methods of making "Puddled Steel," belong to the second; while the now generally practiced pneumatic method known as the Bessemer process, and the "Siemens-Martin Process," are examples of the third class.

Of these three processes, the first supplies the fine steel of the cutlers, the last the softer metal of construction.

Steel of Cementation.—A very usual method of making steel consists in the carburization of bar iron by heating in charcoal, and subsequently working under the hammer or melting in crucibles. The first step in the process is that of conversion or cementation.

The "converting furnace," Fig. 34, as built by the best steel-makers, is a structure of brick-work inclosing a pair of fire-brick boxes, troughs, chests, or pots, as they are variously termed, in which the bars are placed in a bed of charcoal. Beneath these chests is a fire-place, the flames from which envelop the chests while passing to the chimney. These chests are open, and a fire-brick arch is turned over them. The ends of this arched roof are closed in; but openings are left, through which a workman can enter to fill the chests. Flues from the fire-place are led up between and around the chests, and the flames, after enveloping the latter and filling the arch, pass out on either side, entering low chimneys, whence they issue into a tall, open-topped, pyramidal covering of brick-work, which constitutes the main and external portion of the whole structure.

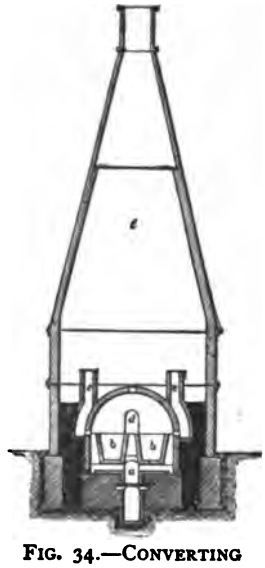


FIG. 34.—CONVERTING FURNACE.

The size of furnace varies somewhat with different makers. The usual size of chest, as adopted by Sheffield makers, is from 8 to 15 feet (2.4 to 4.6 metres) long, and 2 to 3 feet (0.61 to 0.91 metre) wide. The height of the pyramidal stack is usually 30 or 40 feet (9.1 to 12.2 metres); its base has a length of about three times that of the chest, and is twice the width of the pair of chests inclosed. Sometimes two pairs of chests are placed side by side, and the width of base is then about two-thirds its length.

The bars selected for cementation are $\frac{5}{16}$ to $\frac{3}{4}$-inch (0.8 to 2 centimetres) thick, 3 inches (7.6 centimetres) wide, and of such length that they may be conveniently packed in the converting furnace.

A thin layer of coarsely ground charcoal is spread over the bottom of the chest, and on this the bars are laid with spaces between them, which are filled with ground charcoal, while another layer covers the iron; this last layer is, in turn, made the bed for another set of bars. Alternate layers of iron and coal are thus laid down until the chest is nearly filled, leaving room for a thicker layer of charcoal at the top. The whole is finally covered with fine, dry sand, or clay, or is plastered over with "wheelswarf"—the sand from grindstones. Care is taken to exclude the air very thoroughly.

"Trial bars" are placed where they may be withdrawn, through openings left in the chest, for the purpose of occasionally determining, by their examination, the condition of the steel. These openings are plugged with clay, and the manholes in the heads of the arch are closed by bricks.

The powdered charcoal, used as the "cement," is usually made from hard wood, and is sometimes mixed with a small proportion of salt and of wood-ash. The last-named materials are expected to flux the silica contained in the charcoal, and thus to prevent injury of the steel by the absorption of silicon.

The iron used is very carefully selected, if tool-steel is to be made, and is the purest known in the market. Swedish iron is used almost exclusively by British steel-makers, and largely by makers in the United States. The latter also use a few well-tried brands of iron, which are generally made from Lake Champlain or from Lake Superior ores. For machinery steel and cheaper grades, other less costly and less pure ores and irons are used.

The troughs having been charged and closed up, the fire is started and the furnace is slowly heated up, attaining, in two or three days, a temperature of about 2,000° Fahr. (1,095° Cent.), at, or above, which temperature it is held for several days. Steel for tools requiring a considerable degree of car-

bonization, and made from the heavier sizes of iron, is a week in acquiring the necessary temperature, is retained a week or ten days at maximum heat, and occupies nearly a week cooling down; thus, three weeks' time is needed to convert each charge. Each furnace makes sixteen charges per annum. With thinner metal, and a lower degree of carbonization, less time is required; a week of maximum heat answers for shear steel, and four or five days for spring steel.

During the latter portion of this period, the trial bars are occasionally examined, and the gradual change of texture, which indicates the gradual introduction of the carbon as it penetrates the metal, is observed. When the carburization has become satisfactorily complete, the furnace is cooled down and the steel removed.

The bars are then found to have become somewhat increased in dimensions, with a corresponding decrease of density, and are seen to be "blistered" in many places, by the bursting off of a pellicle of surface metal where the carbon oxides have forced their way out. The metal has become hard and elastic, with the granular fracture and all the characteristics of steel. The proportion of carbon is a maximum at the surface, and regularly decreases toward the centre of the bar, the carbon necessarily penetrating the metal, under a gradual decrease in "head," by a slowly progressing flow from the surface. The texture is usually irregular and crystalline, the color white; the grain is finest toward the centre and coarsest toward the surface.

Case-hardening is a modification of this process, in which cementation is only carried so far as to give a steely character to a thin surface layer.

The "cement" used contains less carbon, and often consists largely of nitrogenous matter and hydrocarbons, such as are found in scraps of leather. A common mixture consists of about ninety per cent. carbon, and ten per cent. of carbonate of lime or of potash. The prussiate of potash—potassium ferrocyanide—is often added.

Blister steel, which is the product of conversion by the usual method, is, in consequence of its irregular constitution

and structure, unfit for general use, although sometimes made into cheap grades of tools. It is largely used only for conversion into "shear steel" when containing so little carbon as to weld readily, and into cast steel when containing too much carbon to permit welding. From one to two parts of fuel are consumed, according to degree of carbonization, per part of steel made.

Shear steel is made from blister steel by shearing the bars into short lengths, piling, reheating, and drawing down at a good welding heat, using a flux to insure thorough union into a sound bar.

A common method consists in piling five bars of blister steel, of which one is longer than the others, and serves as a handle by which the mass is manipulated under a tilt-hammer. The bundle is secured by wrapping with wire; the flux is clean sand. As soon as the pile is compacted sufficiently by a few blows of the hammer, the binding wire is knocked off, and the pile is reheated and drawn down to the desired finished size. This process of piling and drawing down greatly improves the metal; the bar of tilted steel is much superior in strength, ductility, and homogeneousness, to the blister steel from which it is made. A repetition of this process gives "double shear" steel, and still further improves it. Double shear steel is used for cheap edge tools and some other instruments, but cannot be used for fine work.

The hammer used for tilting the steel is light and quick working, making 300 or 400 blows per minute, and capable of regulation by the workman.

Tilted steel is usually considered better than rolled; the hammer is almost invariably used in working shear steel.

"**Cast Steel**" is produced whenever fused steel is cast into ingots, or other forms, for the market. It is made by all methods which inyolve fusion, either in the operation of steel-making or subsequently. The tool steels and other fine grades are all cast steels.

The finest cast steels in the market are usually produced either by melting in crucibles and casting blister steels, or by

fusing together, in crucibles, wrought iron, carbon, and flux, and casting in ingots after thorough fusion.

The products of these methods are both known as "crucible steel," and constitute the greater part of all steel used for cutlery, fine tools, and every kind of work for which metal of the greatest possible purity and uniformity of composition and character is demanded.

In some few cases, these steels have now been displaced by the product of the Siemens and the Bessemer processes, which latter have the advantage of greater cheapness.

Crucible Cast Steel, as made by melting blister or cemented steel to give it a homogeneous character, is the standard steel for fine tools. This process was introduced in Great Britain, and was probably invented, by Benjamin Huntsman, about the year 1770. He was then living near Sheffield.

The "crucibles" or pots (Figs. 35, 36, 37) in which steel is melted, as used at Sheffield and by many American makers, are composed of a fine and very refractory clay. They are about 16 inches (40 centimetres) high, 7 or 8 inches (17 to 20 centimetres) in greatest diameter, and weigh about 25 pounds (11.3 kilogrammes). To make each pot, 20 or 22 pounds (9.1 to 9.9 kilogrammes) of new clay, 1 or 2 pounds (½ to 1 kilogramme) of cinder, and 2 or 3 pounds (1 to 1.3 kilogrammes) of old pot material are ground together very thoroughly, and 5 or 10 per cent. of ground coke-dust is often added. The material is mixed and kneaded by treading under foot on the "treading floor" 8 or 10 hours, and is then ready for use. The pots are then formed by hand, and are allowed to dry a week or more before "annealing" them by slowly and steadily raising them to a bright red heat, and as slowly and steadily cooling them.

FIG. 35.

FIG. 36.

FIG. 37.

In the United States, crucibles are very extensively used in which the clay is mixed with a considerable proportion of graphite. These pots wear better than those of clay. They yield some carbon to the metal, and this is compensated by a corresponding reduction of the charge of carbon introduced. These crucibles are often larger than those first described, and carry from 40 to 70, or even 80 pounds (18 to 36 kilogrammes) of steel.

Steel-melting furnaces (Fig. 38) are usually plain fire-brick structures with rectangular chambers, each of a size sufficient to permit the introduction of two crucibles. These chambers are arranged side by side before a common flue, and with their tops level with the floor. The ash pits are reached from a trench or "cave," extending along the front of the row. A high chimney gives the sharp draught which is essential to secure the intense heat demanded in steel melting. Coke is the usual fuel.

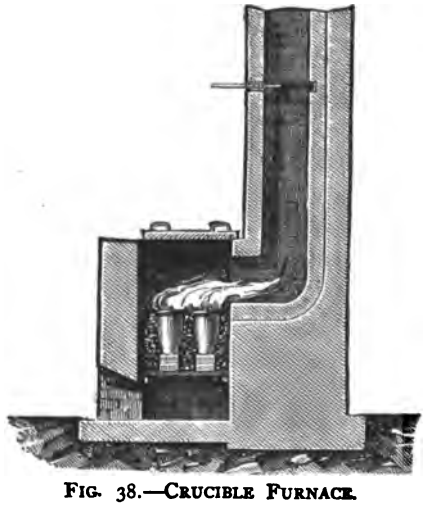


FIG. 38.—CRUCIBLE FURNACE.

The crucible is charged with the proper weight of metal and carbon as required, together with a small percentage of spiegeleisen or other manganese-bearing materials after they are placed in the furnace.

The use of manganese was first practiced by Josiah M. Heath, who patented the process in 1839; but it is probable that manufacturers sometimes used fluxes containing manganese at an earlier date, without, however, knowing the reason of their efficiency.

The precise action of manganese is not fully determined. Without it, only the purest known irons could be used in making steel, and even those were not usually capable of

being converted into a thoroughly malleable product. By the addition of a small quantity of manganese, which rarely exceeds in amount, in the cast steel as finally produced, one eighth of one per cent., the metal becomes easy to work, and in every way improved. It acts as a corrective of red shortness and an "antidote" to sulphur; but this action takes place, however, without removal of the sulphur. Its effect is to produce hardness without great brittleness, while giving the steel greater malleability at high heats. Manganese also assists by reducing liability to the formation of blow holes in the ingot by absorption of oxygen.

The pots are set in the furnace upon stands made of clay, which sustain them clear of the grate bars. They are charged with the broken blister steel and manganese, and sometimes with a flux of broken bottle-glass, are carefully covered with a lid of crucible clay, and allowed to remain at a temperature exceeding, probably, 3,600° Fahr. (about 2,000 Cent.) an hour or an hour and a half, the furnace being, meantime, kept well supplied with fuel and at the highest temperature possible.

When the steel, at the end of this time, is found to be thoroughly melted, it is "teemed," *i. e.*, poured off. The "puller out," protecting his clothing and person by coarse bagging or cloth saturated with water, stands directly on the top of the furnace and raises the crucible from its bed with a pair of large tongs fitted with handles 4 feet (1.2 metres) or more in length, and swings it out into the "teeming hole," as it is called, a square, iron-lined hole in the floor, large enough and deep enough to take it in.

The melter next takes the pot in the "teeming tongs," and pours the molten metal into the ingot mould, a helper standing by with a "flux stick," to prevent the escape of flux with the steel.

The ingot has either an octagonal section or a section like a square with the corners removed; it tapers slightly from end to end. The mould is in two halves, and is coated within with a preparation containing soot or other form of carbon. The ingot, when removed from the mould, is "topped," *i. e.*, a small piece is knocked from the upper end

with a heavy hammer or sledge, and inspected by an experienced judge of the metal, who assorts the several qualities into standard lots, each of which is of a definite "temper." With care and skill, differences of less than one tenth of one per cent. carbon are noted, and, in some cases, selected tool steels of high grades have been distinguished by the eye when differing one twentieth of one per cent. in proportion of carbon.

The ingots are finally hammered and rolled into forms suitable for the market.

The "*mixture*" introduced into the crucible has a composition which is determined by the character of the available materials and of the product demanded.

It usually consists of either blister steel produced by the cementation process, with a small percentage of carburet, or of peroxide, or of other compounds of manganese, with some suitable flux; or it is chiefly selected iron of fine quality, with a definite proportion of charcoal and of manganese and flux.

Chromium, titanium, tungsten, and other elements, are sometimes introduced, as in the production of chrome steel or of titanium or tungsten steels, so called.

The principal properties of the crucible steels and of carbon steels generally will be discussed in a later chapter. In structure they are usually very uniform and homogeneous, granular, compact and dense, and are generally found better fitted for purposes demanding fine quality than are other kinds of steel. Although each crucible contains but a small quantity of metal, immensely large castings are made by fusing the metal all at one time in a large number of crucibles, which are systematically emptied into a common reservoir or mould. Castings weighing many tons are sometimes thus made.

Crucible steels are principally used for cutlery and other tools; but they are sometimes made with so low a proportion of carbon as to be properly denominated "homogeneous iron," and are then used for boiler-plates, axles, lining tubes for ordnance, and for parts of machinery in which homo-

geneousness, ductility and strength are desired in combination.

Wootz, or Indian steel, is made by the second of these crucible processes, as already described.

Cast steels owe their excellence to the care taken in the selection of the raw material used, to the extraordinary skill acquired in assorting it, and to the great uniformity of quality and texture insured by fusion. The harder kinds of cast steel made from cement steel require the addition of carbon in the crucible when the process of cementation is interrupted before the degree of carburization demanded for the cast steel is fully attained.

As steel in fusion absorbs oxygen freely, the exclusion of the air from the melting pot is important. The higher the temperature, and the less the proportion of carbon, the more freely is gas absorbed. The crucibles, when of purest clay, can only be used a few times. Those of mixed clay and graphite are more durable. In pouring, the temperature should be as low as possible, without incurring danger of premature solidification. The moulds should be warmed before they are used, should be kept hot until filled, and should then be promptly and carefully covered.

Puddled steel is often remelted for large castings. The hardness, the lack of ductility, and the diminished welding power of the steels make it necessary to observe greater precaution in working them than in the working of iron, and their susceptibility to injury by prolonged high temperature compels greater care in heating them. The ingots are worked at from a moderately high red heat to a low yellow heat; at too high a temperature they burn, scintillate, and lose carbon; at too low temperatures they crack, and refuse to weld.

"**Open Hearth Cast Steel**" is produced by melting in large quantities on the hearth of a reverberatory furnace. The class includes steels produced by the Siemens-Martin process, to be described later. The Siemens furnace is used as a melting furnace for steel, both when melting in crucibles, and when melting on the hearth in masses of four

or five tons (4,064 to 5,080 kilogrammes). This latter is the most practicable method of producing large ingots and castings. By the old method the melting of a ton (1,016 kilogrammes) of steel requires often three to four tons (3,048 to 4,068 kilogrammes) of coke; by the Siemens furnace the work is done readily with a ton (1,016 kilogrammes) or less of the cheapest fuel, the breakage of crucibles is greatly reduced, and the lining of the furnace is better preserved.

Steel, melted on the Siemens open hearth, requires the consumption of three-quarters of a ton (762 kilogrammes) or less of fuel per ton of metal, and the rapidity of melting is very much greater than in pots.

The high temperature required for steel melting has precluded the use, to any considerable extent, of the ordinary form of reverberatory furnace, and the Siemens furnace is the only one which has, up to the present time, been adopted for this work with satisfactory and general success.

Steel making on the open hearth of the Siemens furnace, as proposed by C. W. Siemens, was first practiced in France with commercial success, by the Messrs. Martin, in 1865. The process is generally known as the *Siemens-Martin process.*

This method is sometimes regarded as one of decarburization of cast iron by the addition of uncarburized metal; it is perhaps more correctly a method of imparting a definite proportion of carbon to wrought iron by mixture, in fusion, with cast iron. It is extensively practiced, and is the principal, and, practically, as yet, the only competitor with the pneumatic process in the production of soft and low grade steels. It may be used for the production of tool-steels, but it is seldom so applied.

For this process the bed of the reverberatory furnace is given a form somewhat resembling that of the puddling furnace, and the lining, or bed, is made of selected clean siliceous sand, containing some alumina or magnesia. Bauxite, containing 65 per cent. alumina, 15 per cent. silex, 5 per cent. iron-oxide, and some water in combination, makes a good lining also, so long as it can be retained in place.

A charge of scrap iron, or old rail-ends, either iron or

steel, is introduced after the furnace has been brought up to a full white heat, and to this is added the required amount of cast iron. The weight of a charge is usually between four and five tons (4,064 to 5,080 kilogrammes). The following represents a fair charge:

	Pounds.	Kilogrammes.
Pig-metal; No. 3, or white iron.....	5,000	2,272
Wrought iron scrap, or puddle bar.....	4,500	2,043
Spiegeleisen.....	500	227
	10,000	4,542

A half ton (508 kilogrammes) of good coal is here required to make a ton (1,016 kilogrammes) of steel.

As practiced in some French establishments, the following are the details of the process as given by Kohn:

The pig and scrap iron and steel are heated separately before charging into the steel furnace. A charge of about 2,000 pounds (900 kilogrammes) of the heated pig metal is first placed on the hearth and melted down. The scrap steel, and wrought iron, heated to a white heat, are next added in charges of 440 pounds (about 200 kilogrammes) at intervals of a half hour, each charge being melted down and thoroughly incorporated in the bath before the next is added.

Recarburization becomes complete in six or seven hours, and the mass becomes pasty, as in puddling, after the fusion of 4,840 to 5,280 pounds (2,200 to 2,400 kilogrammes) of wrought iron.

Recarburization is then effected to the customary extent by the addition of cast iron, in, usually, four charges of 440 pounds (200 kilogrammes) each, this metal being similar to that first charged, and generally containing some manganese.

The bath is covered with a slag of blast-furnace cinder, rendered more silicious by the addition of sand, and the metal is kept fused any desired length of time while adjusting its quality. The total weight of metal charged, as above, is usually about 8,800 pounds (4,000 kilogrammes), and the product is not far from 8,140 pounds (3,700 kilogrammes). The exact proportions will vary with the composition of

the materials used, and with the character of product demanded.

The charge is melted down under an oxidizing flame, and the carbon is thus partly removed by burning out, and the exact proportion required is then secured by dilution with malleable metal. The molten cast metal forms a liquid bath on the hearth, into which the wrought iron gradually dissolves. The metals having been thoroughly fused, the process is continued until samples taken from the furnace and tested exhibit the desired quality, or until they indicate complete decarburization. In the latter case, the spiegeleisen, or other manganese-bearing material is added, and tests of samples are again taken to determine quality.

If the metal is not now of precisely the quality wanted, the addition of cast iron or spiegeleisen, or of wrought iron, is continued, as required, until the steel is found to be of the exact character demanded; and it is then tapped off into ingot moulds.

The cast iron should be carefully selected, and especially free from phosphorus when steel containing considerable carbon is to be made. The wrought iron should be selected with similar care, when fine steels are to be produced, and the spiegeleisen should always be very free from either phosphorus or sulphur; it usually contains ten per cent. or more of metallic manganese. The softer the grade of steel made, the richer should the spiegeleisen be made in manganese, and the lower its proportion of carbon.

For steels containing a very small proportion of carbon, a comparatively high percentage of phosphorus, or other hardening element, is admissible.

The cost of the steel will vary greatly with the cost of scrap metal and of cast iron, but is usually, in gross, not far from that of making steel by the pneumatic process.

Each furnace requires three furnace-men, and outside labor to handle the product. The cost of repairs varies greatly with the management. It should be a small item. The total cost of steel per ton (1,016 kilogrammes) should not exceed the value of ten days' laborers' work.

This process possesses some peculiar and important advantages. The steel lying on the open hearth, under a flame which may be made oxidizing, deoxidizing, or neutral at pleasure, may be sampled at convenience, retained in fusion any desired length of time, and treated in any way that may be necessary in the modification of its quality.

The plant is simple, inexpensive, and can be, from time to time, enlarged, as may be considered expedient, without limit. The range of quality of material available for use is less restricted than in some other processes, and in making "mild steels"—"ingot irons"—as little as 0.10 per cent. carbon can easily be reached.

The "Direct Process" of steel making, as practiced by Siemens, is similar to that already described as producing malleable iron, except that the final step in the process is the addition of spiegeleisen, in the manner described above, to recarburize the iron to the desired degree.

After the addition of this spiegeleisen, the metal is sampled and tested, and, if found of proper quality, is tapped off. If it requires an additional dose of carbon or manganese, more pig-metal or more spiegeleisen is added, and, if the carbon or the manganese is in excess, the bath is modified by addition of scrap iron, or of ore, and by exposure to the oxidizing flame. When found to be precisely of the character demanded, the steel is tapped off into ingot moulds, and finally sent to the rolling mill, or shaped under the hammer.

The process above described is, in greater detail, given by its inventor, in the larger work.

In the Bessemer process, carbon, silicon, and manganese appear to be eliminated uniformly. In the open-hearth process, the degree and the time of elimination are quite different. During the time the charge is passing into the fluid state, carbon, silicon, and manganese are all more or less oxidized, leaving usually about 50 per cent. of the total amount contained in the charge, this quantity varying slightly with the temperature of the furnace. As soon as the whole of the charge is fluid, the carbon remains almost, if not entirely, unchanged, until the whole of the silicon and manganese are oxidized.

The pig iron most suitable for the open-hearth process —the sulphur and phosphorus being low—is that containing the least carbon and silicon. In the first place, it contains a higher percentage of iron, and, in the second, it does not require to be so long in the melting furnace before the metal is completely decarbonized. Moreover, pig iron containing a large percentage of silicon, although it is all oxidized, invariably yields inferior steel. More than 0.50 per cent. of manganese is objectionable, not only on account of the delay it causes, but because of the destruction of the silica bottom by the formation of a fusible silicate of manganese. From long experience, it has been found that steels from different brands of hematite pig iron, chemically the same and made from the same ores, not only act differently in the furnace, taking more time, cutting the bottom, etc., but in their finished state show a marked difference in their tensile and other tests. When first noticed, this was attributed to some defect in the mode of analysis, which failed to detect minute traces of elements possibly derived from the coke or limestone used in their manufacture; but it was found that two cargoes of pig iron, of different brands, both of which worked in a most unsatisfactory manner by themselves, gave, when mixed in equal proportions, results which were everything that could be desired. Others invariably gave good results *per se*, and by mixing as many brands as possible uniform results may be obtained.

Experiments made at Landore show that no metal added to the bath of steel has the slightest effect, so far as the elimination of sulphur is concerned, and manganese is the only metal that will counteract it. Manganese is indispensable in steel made by an oxidizing process. An ingot from a charge composed of Swedish pig iron and puddled bar made from the best hematite pig containing no manganese, will break into pieces at the first blow of a hammer, whilst a similar ingot containing 0.08 per cent. manganese will forge. Tungsten, alloyed with steel in small amount appears to harden it without detracting from its toughness.

The Fluxing of the Steel, more especially with a view to the removal of phosphorus, when that element is present in objectionable quantity, is a subject which has attracted much attention from metallurgists.

Henderson's process, applied to steel making, is an example of such an effort. In this process, fluxing is effected by the use of the fluorides and oxides, fluor-spar and iron oxide, as in the puddling process introduced by the same metallurgist. These materials are usually applied as a fettling on the bottom and the sides of the furnace, but may be injected in a finely divided state into the bath of molten metal. Oxide of manganese is added with oxide of iron; and any lime present, or added in the process, assists in the formation of cinder.

The character of the steels made by the above described methods is very variable, and depends upon the character of the materials found available, and upon the skill with which the work is done. The steels thus made, and especially those produced by the open-hearth process in general use, are generally "low" steels, such as are best adapted to those purposes for which iron was formerly exclusively used, and should be classed as "ingot" iron, rather than as ingot steel.

The Siemens-Martin process is peculiarly well adapted to making fine grades of such metal. It is more or less economical than the Bessemer process, according to the value of the scrap wrought iron, although the continually increasing production of the standard plant in the latter branch of manufacture is making it more difficult to compete when extreme exactness in securing the specified grade is not demanded.

The Pneumatic Method of Steel Making, generally known as the Bessemer Process, is the most extensively practiced and the most productive, by far, of all known methods of making ingot metal.

It has been known since the time of Cort that the agitation of molten cast iron, in presence of oxygen, will produce combustion and removal of carbon, and the reduction of the cast iron to the state of malleable iron or of steel.

The pneumatic process secures such an agitation, and a

very thorough intermixture of the fluid iron with the oxidizing atmosphere, by causing the latter to stream up through the molten mass in innumerable minute bubbles; the rapid combustion thus secured is sufficient to supply all heat needed, not only to retain the metal in a fused condition, but, also, so rapidly and so greatly to elevate its temperature during the operation, that the product, even when entirely deprived of carbon, remains a perfectly fluid wrought iron in the converting vessel.

The process was invented independently by Henry Bessemer, in Great Britain, and by William Kelley, in the United States. Patents were issued to both by the U. S. Patent Office, and their interests were combined when the manufacture was established. Bessemer's patent dates from November, 1856, and Kelley's from January, 1857, the latter having been granted after a declaration of interference. Kelley at first forced air under high pressure downward into the mass of molten metal in comparatively few and large streams; Bessemer began in a somewhat similar way, treating steel in crucibles. In both cases, the metal was converted so slowly that chilling took place before the work was completed. When the same operation was conducted in the more effective method now familiar to engineers, it became at once a practically useful process. Since the date of the early patents, this manufacture has grown to enormous proportions. It is the source of the greater part of the "steel" rails now used; it furnishes a large amount of "steel boiler-plates."

The Plant and Apparatus standard in the United States may be taken as illustrative of a highly efficient arrangement. It owes its excellence largely to the skill and intelligence of the men who have developed it in this country, mainly to the late Mr. A. L. Holley, who designed the works and nearly all peculiar details observable either in arrangement of plant or form of apparatus.

It usually consists of a pair of "5-ton converters," with accessory apparatus. A pair of such converting vessels was originally expected to make about 80 tons (81,280 kilogrammes) per day, or 25,000 tons (25,480,000 kilogrammes)

per annum. The charge has been gradually increased, and the number of heats as well, until 7 tons (7,112 kilogrammes) per charge, and 60 heats, or even 80, per day, giving a production of 100,000 tons (101,600,000 kilogrammes) per year, has been obtained from this plant.

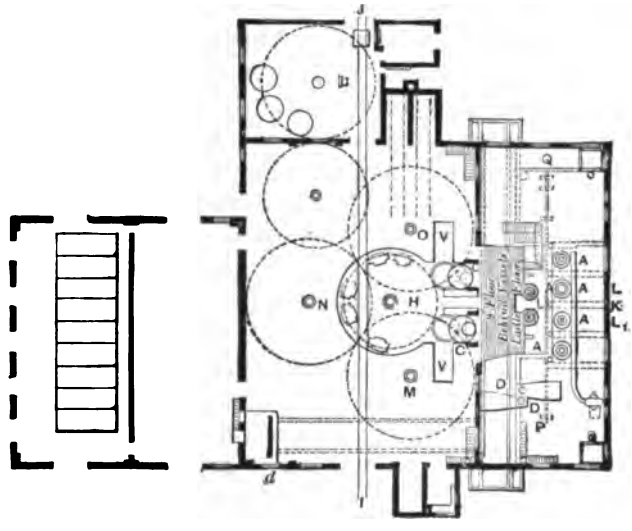


FIG. 39.—AMERICAN 5-TON BESSEMER PLANT.

The general arrangement of plant is shown in the accompanying drawings. Fig. 39 represents the ground plan as designed by Holley, and Fig. 40 is a section laterally on the centre line of the pit surrounding the converter.

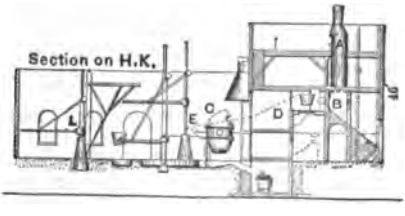


FIG. 40.—SECTION OF BESSEMER WORKS.

The cast iron is melted in cupolas, *A*, *A*, *A*, *A*, Fig. 39 in plan, and seen in elevation in the section resting upon the second floor of the converting house, at the right of the converters, *C*, *C*.

Materials are hoisted from the lower levels by hydraulic

elevators placed at each end of the charging floor, the one for fuel, the other for metal. The barrows on which the charge is transported are of iron, and carry about a ton (1.016 kilogrammes) of iron each, or ¾-ton (772 kilogrammes) of coal. One barrow for each 7 or 8 tons of steel made per day is sufficient.

The metal is charged with the limestone required for the flux, and with about one sixth or one eighth its weight of fuel. This small consumption of fuel is one of the sources of economy secured by this plant. Reverberatory furnaces, often used elsewhere for melting, are less liable to injure the product by the introduction of sulphur and phosphorus when these elements are present in fuel and flux; but they are vastly more expensive in operation. With good fuel and pure limestone the cupola gives good economical results, however, without injury to the iron.

The cupola furnaces (Fig. 41) used are made especially for this work, and, as designed originally by Mr. J. B. Pearse, are made with much greater depth of hearth, greater tuyere area, and straighter boshes than the foundry cupola, in order to fit them to carry more iron and to melt it more rapidly. A usual form is of elliptical transverse section, 3.5 by 6.5 feet diameter (1.1 × 2 metres) and 13 or 15 feet (4 or 4.6 metres) high, and with a total cross-section of all tuyeres of about 200 square inches (0.13 square metre). In charging these cupolas a bed is first laid of about 2½ tons (2,540 kilogrammes) of fuel, above which is placed 1¼ tons (1,245 kilogrammes) of pig iron, then a half ton (508 kilogrammes) of fuel, and above that 1¼ tons (1,245 kilogrammes) of iron, and so on until the cupola is full to the charging door. A little limestone is now and then added as a flux. Such cupolas will melt 50 tons (50,800 kilogrammes) of iron in eight hours. From

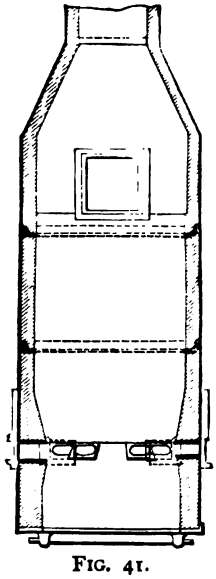


FIG. 41.

the cupolas the iron, when ready, is tapped into 12-ton (1,392 kilogrammes) ladles standing on balanced scales, where it is weighed and where it remains until the converter is ready to receive it. This arrangement permits the determination to be made of the amount of spiegeleisen needed, and the great capacity of the ladles permits the manager to use them as reservoirs into which the molten iron from the cupola can be run instead of lying in the cupola hearths and interrupting the melting process when they become too full.

Air is supplied to the cupolas by fan-blowers, at a pressure of nearly or quite one pound per square inch (0.07 kilogramme per square centimetre). The cinder and other material dumped from the cupola slides down the inclined plane *B*, and are deposited near the cinder-mill, in which they are ground; they are then assorted, and any iron found in the mass is saved and remelted. The cinder is cooled and broken up by a stream of water from a hose.

From the ladles, *L*, *L*, the molten iron is poured into troughs, *D*, *E*, or runners, of which an upper movable section, *D*, is attached at one end to the ladle *L*, while the other end is carried on rollers, thus being given a power of self-adjustment as the ladle turns, and while discharging the stream of molten iron into a single lower fixed section, *E*, which receives it from both ladles. The latter has two branches, each leading to a converter, so that the metal can be charged into either, as required.

In this "melting department," as this portion of the steel-works is called, are also placed the furnaces, *D*, *D*, in which the spiegeleisen is melted. These are usually reverberatory furnaces; cupolas, although sometimes used, are found less well adapted to this work, since the metal is often kept in the molten condition for so long a time, that it might, in the comparatively cool and unheated

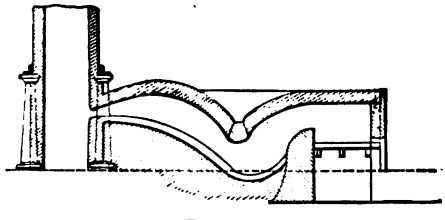


FIG. 42.

hearth of a cupola, get chilled. Where, as in the more productive works, the demand for spiegeleisen very frequently recurs, cupolas give good results; they are in all cases vastly more economical of fuel than the other furnaces.

In American works the reverberatory furnace, Fig. 42, is usually built with a slope, on which the metal is charged, near the flue, where the flame impinges most violently, and where it will be most rapidly melted, although it is then most liable to injury by oxidation of its manganese, which element has an exceedingly strong affinity for oxygen. In Europe, the furnace, Fig. 43, is often so built that the metal may be charged upon the slope of the bed, near the bridge-wall, where, although melted less quickly, it is less liable to oxidation.

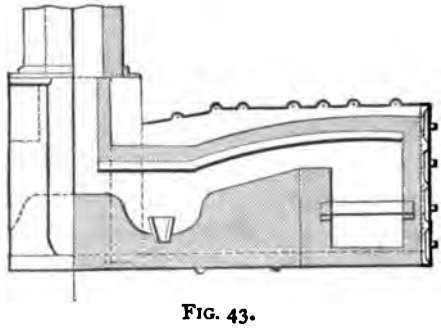


FIG. 43.

The space below the furnaces, as shown in the figures, is large enough to permit storage of raw materials for linings and repairs, and all common stores. A "crusher" and set of rolls on the cupola floor are used for crushing the materials to be mixed for linings. A wide gangway is carried entirely through this building on the ground level, and gives a roadway for the carriage of material.

The "converting department" is placed in front of the melting department, and here two converters are mounted side by side, above the general ground level. In European works, Figs. 44, 45, they are usually placed in a pit sunk in the floor, and opposite each other, an arrangement which is less convenient, and causes the workmen to suffer more from heat than where everything is above ground. In front of the converters, *A*, is the casting pit, in the centre of which is a hydraulic crane, *C*, and around which are three other cranes, by which the ingots and ingot-moulds, *D*, are handled. Nearly on a level with the trunnions of the converters is another

floor, on which workmen may stand, and where materials can be placed while repairs are going on; it is reached from the hoists, which open on this level, and the workmen enter upon it from the melting house by a side passage, when firing or repairing the converters, or when inspecting the converter bottoms. The cranes, *K*, swing completely around, the middle one handling all ladles and ingots in the pit, and transferring its load within reach of the other three, which latter convey it to the storage space, near the pit, or to a carriage, which traverses a railway of 30-inch (76.2 centimetres) gauge, passing over the scale, on which the weighing is done. At the left of the latter is the weigh-house, where, also, are rammed the converter-bottom linings.

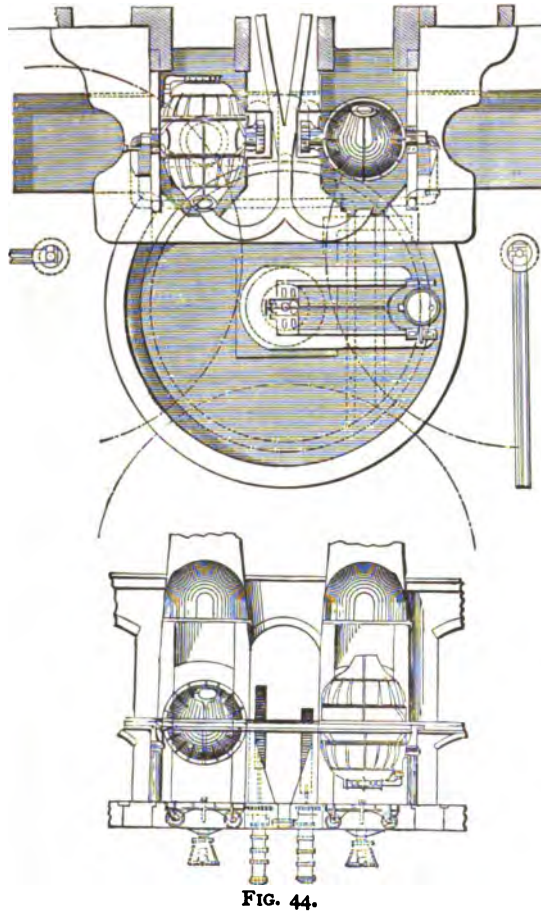


FIG. 44.

The buildings at the extreme left contain the boilers, engines, and pumps. The engines used for blowing the air through the converters are of various forms. The most usual arrange-

ment includes two independent engines, with steam and air cylinders and fly-wheels complete, in order to avoid the entire cessation of work that must otherwise follow upon the break-down of a coupled engine. Condensing engines 42 to 44 inches (1.07 to 1.12 metres) in diameter of steam cylinders, and about 54 inches (1.37 metres) in diameter of air-cylinders, with a stroke of piston of 5 feet (1.5 metres), and working steam of 60 to 70 pounds per square inch (4.2 to 4.9 kilogrammes per square centimetre), are adopted with a "5-ton (5,080 kilogrammes) plant."

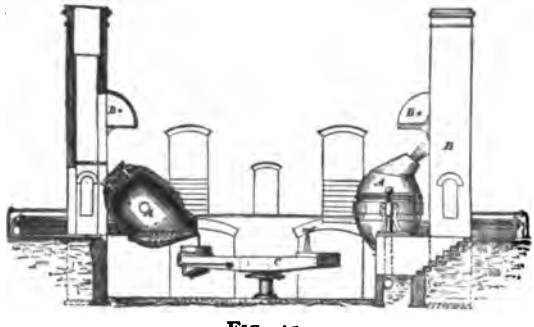


FIG. 45.

The water supply for the hydraulic cranes, and for the apparatus handling the converters and the hoists, is obtained from direct-acting steam pumps forcing water under a pressure, at the accumulator, of 350 to 400 pounds per square inch (24.6 to 28 kilogrammes per square centimetre).

The converter is the only part of the plant which demands more minute description.

In the sketch, Fig. 47, is seen the lower part of this vessel, the general outline of which is seen in the above illustrations already described. The bottom of the converter consists of a hollow detachable box, into which the

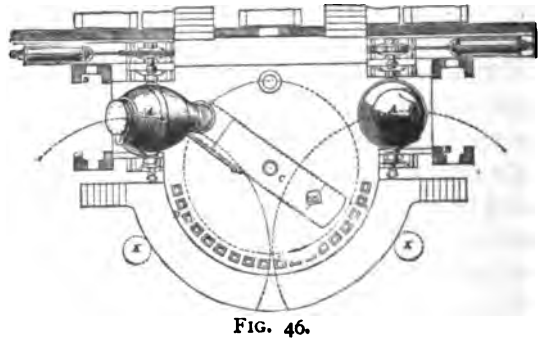
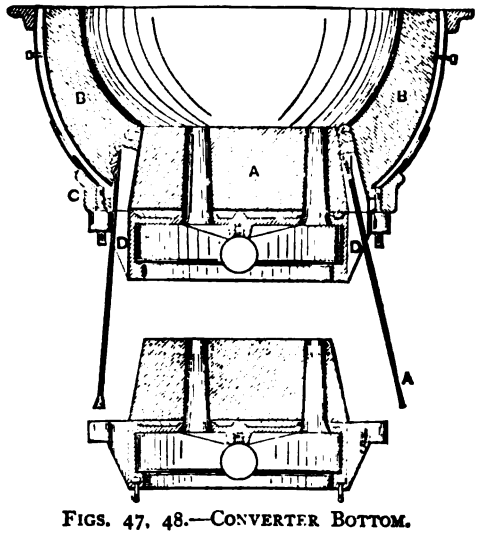


FIG. 46.

blast, which enters at the trunnion, is conveyed by side-pipes, and from which it rises through a large number of small holes, which traverse the lining mass, *A*, which protects the bottom from injury. The sides of the converter are also covered by the thick, infusible lining, *B*, *B*, of ganister or of ground siliceous stone, mixed with 10 to 12 per cent. fire-clay. The composition of ganister, and of the artificial substitute in use, is about: silica, 93; alumina, 4, with 3 per cent. of other substances. The mass, *A*, is moulded upon the top of the blast-box, as seen below, and the imbedded tuyeres are firmly held by adhesion in the mass, and steadied also by the metal plate, which forms the top of the blast-box.



FIGS. 47, 48.—CONVERTER BOTTOM.

When the lining is worn down, and the tuyeres become too short for further safe working, the bottom is removed, and another, which has been meantime prepared, is put in its place as shown in the sketch. An open space, *C*, *D*, is left in order that no impediment may arise from too close a fit, and this space is tamped full by driving through an annular space, *D*, which is left open by the construction adopted. This space is three or four inches (7 to 10 centimetres) wide, and the filling is a mixture of ganister and fire-clay worked moist and driven snugly in place. This is done while the converter lining is still red hot, and occupies from three quarters to one hour after the opening has been trimmed and smoothed out.

The bottom requires frequent replacement; the con-

verter itself requires less frequent relining. The latter is divided into three separate sections, which can be lined independently. The relining of the upper and lower parts is usually done in the weigh-house. The middle part, being fixed by the trunnions, is relined in place.

These linings are worn away by both mechanical wear and by chemical action. The replacement of the converter bottom, when worn, does not cause delay, nor does it reduce production; but the relining of the converter itself often causes serious loss by stopping all work. During its working period, however, 60 to 80 charges per day of 24 hours can be made into steel, and 60 charges have been made in 12 hours.

In Holley's latest form of converter, the trunnion ring is detachable, and the whole converter can be removed for relining, another being kept ready to take its place at the removal of the first.

Of the pig metal melted in the cupola, about 85 per cent. appears in the form of ingot steel, the remaining 15 per cent. is lost by oxidation and by the formation of "skulls" and slag. A nominally 5-ton (5,080 kilogrammes) plant produces, usually, 6,000 to 8,000 tons (6,096,000 to 8,128,000 kilogrammes) per month, and sometimes greatly exceeds this figure. This rate of production has been steadily growing from the beginning, and is still increasing.

Operation.—The following is, in brief, the method of operation: The cast iron is melted in the cupola—or, if fears are entertained of the introduction of injurious elements from the fuel, in a reverberatory furnace, and after complete fusion, it is transferred to the converting vessel.

Before the iron is run into the converting vessel a fire of charcoal or coke is started within it, and a gentle blast turned on until the interior has been raised to a white heat. It is then ready for the charge, which has meantime been melted in a cupola or air furnace.

To fill the converting vessel, it is turned on its trunnions until the charge may be run into it, and so far that the molten metal shall not fill the tuyeres. The blast then is turned on at a pressure of from 15 to 25 pounds per square

inch (1.4 to 1.8 kilogrammes per square centimetre) according to the depth of the charge; it enters at the bottom in a multitude of fine jets, through orifices about a quarter of an inch (0.6 centimetre) diameter. The vessel is then turned into the vertical position, and the blast, permeating every portion of the liquid metal, seizes upon the oxidizable elements present, burning them out.

The operator watches the process with great care, observing the indications of the pressure gauge, the sound issuing from the converting vessel, the character of the flame, sparks and smoke issuing from the nozzle, and noting the duration of the phenomena exhibited as the operation proceeds.

At the instant that the blast commences passing through the metal, oxidation begins. The air, expanding violently as it rises, dividing into large globules or minute bubbles, seizes, as it goes, first upon the silicon. As the current passes from the converter to the chimney, it exhibits but little smoke, and carries with it large and brilliant sparks.

The metal, instead of being cooled by the great volumes of cold air forced through it, grows hotter and more liquid as combustion proceeds at the surfaces of the innumerable continually rising air-bubbles.

The whole mass becomes agitated until the vessel, and often its foundation, trembles. A regular muffled clapping sound is heard as the iron thrown up by the blast falls back again, and in six or eight minutes from the commencement of the process the sparks diminish suddenly in number, and a flame appears, first dull and red, but soon changing to a long tongue of fire, as the air, finding no more silicon with which to combine, seizes the carbon.

The silica formed in the first stage of the process combines with any oxide of iron then or subsequently present, and with it makes a glassy cinder that covers the surface and assists in retaining the heat of the iron.

As combustion progresses, the flame becomes, for a short time, partially obscured by smoke; then it clears again, and a voluminous clear white flame indicates that the graphite has all been burned away, that the combined carbon has

begun to leave the iron, and that if the process is not checked at the proper moment, the iron itself will soon begin to burn.

As the end of the operation approaches, some loss of iron is unavoidable. The temperature has become much higher than the melting point of cast iron; for the converter now contains a mass of nearly pure wrought iron, perfectly fluid, its whole mass pervaded by minute globules of air, which no longer finds sufficient combustible matter to satisfy its affinity unless it takes the iron itself. After the appearance of the white flame the detonations gradually cease, and after about fifteen minutes from the beginning the flame grows irregular and fitful, and then suddenly disappears.

The process is completed; the converting vessel is rapidly turned down, and the blast shut off. The iron is found, if then examined, to be almost perfectly pure malleable iron, which may be run into ingots and passed through the rolls or worked under the hammer.

As a low steel is, for most purposes, far more valuable than any wrought iron, and as the iron in its present state is "short," in consequence of the presence of iron oxide and of gas, the charge is next recarbonized to a certain extent before being removed from the converter. For this purpose some franklinite, spiegeleisen, or other manganiferous cast iron is melted in a cupola before the conversion of the charge is commenced. As soon as the process of decarbonization has ceased, a quantity of the recarbonizing material, in such proportion, usually 5 or 8 per cent., as is determined by the kind of steel required, is added to the purified iron.

The materials alloying perfectly, the carbon, manganese and silicon are diffused uniformly in proper proportion throughout the charge, and thorough intermixture is insured by blowing it in the converter when necessary. The whole time occupied in changing into steel a charge of ten or twelve thousand pounds (4,545 to 5,454 kilogrammes) of cast iron and forming it into ingots is less than half an hour.

The operation might be shortened, and the recarbonization avoided, by stopping the process before the carbon is all con-

sumed, and considerable quantities of cheap steel have been sometimes made in this way. But the rapidity with which combustion proceeds renders the method unreliable and the product variable in quality, and it is found far more satisfactory to complete the decarbonization and then to add a known quantity of carbon by the method already described.

The steel from the converter is run into moulds, where the ingots rapidly cool, and in 30 or 35 minutes the largest masses are taken out and placed in a heating furnace or a "soaking pit," and are kept at a sufficiently high temperature to work freely while the interior cools to such an extent that the ingot may be safely carried through the rolls or forged to the desired shape under the hammer.

The capacity of the converting vessels has in Europe been gradually increased until some English manufacturers are converting 12 tons (12,192 kilogrammes) at a single charge; but converters of 5 tons (5,080 kilogrammes) and of 7½ (7,620 kilogrammes) tons capacity are most usually employed, and larger vessels are not called for in the United States.

The result of a moderately productive week's work of one pair of 5 ton (5,080 kilogrammes) converters gave in one instance a product of nearly 4,000 tons (4,064,000 kilogrammes), and produced 325½ (330,538 kilogrammes) tons waste scrap. The product of an American plant, as here described, has in one case been reported as often above 13,000 tons (1,320,000 kilogrammes) of ingots for one month's work, and yielding 11,000 (11,176,000 kilogrammes) tons of finished product (rails).

The steel, when completely recarbonized, is, as above stated, poured off into a ladle, which distributes it to the ingot-moulds, which are made of gray iron of open texture, washed within with clay or plumbago, and set in a circle about the outer circumference of the ingot pit.

The ingots so produced are a foot (0.3 metre) or more square at their lower ends, tapering to a cross-section ten per cent. less at the top, and each ingot is usually so proportioned as to furnish material for either two or three rails,

where railroad metal is to be made, in order to save in the weight of rail ends returned as scrap.

The large ingots also furnish better steel, as they are worked more in the process of rolling. They are 3½ to 4½ feet (1.06 to 1.37 metres, nearly) in length, and usually weigh from 1,300 to 1,600 pounds (590 to 726 kilogrammes). Even heavier ingots are sometimes made. The ingots are sometimes hammered, but oftener rolled, into blooms of about one-fourth their original section, and are then sent to the rail-train.

Where the blooms are rolled, a "three-high mill" is generally employed, which is somewhat similar in general plan to those already described, but which are specially adapted to their work by ingenious and important details designed by their builders or the engineers of the works. In some of these mills, as designed by Mr. George Fritz, the movements of the bloom on the table, including the entering of it into the rolls, the lateral shifting, and even the turning of the piece, are all done by steam power.

In the United States the rail-train is usually made in three lengths of 21-inch (53 centimetres) rolls, or of two lengths of 24-inch (61 centimetres) rolls; they are "three-high," and are very strongly built; they can deliver 150 tons (152,400 kilogrammes) or more of finished rails per day of 24 hours.

The Steel made by this Process is principally used in the manufacture of steel rails; a considerable amount is employed for boiler-plates, and also for axles and for running parts of machinery.

Good steel for either of these purposes is so low (0.20 or 0.15 per cent.) in carbon that it should properly be classed as ingot-iron. The desired strength, toughness, and freedom from liability to harden with changing temperature when placed under such conditions, for example, as are met with in boiler-construction and working, can only be secured by care in the selection of the best of ores, and choosing the best of pig-metal for the preparatory processes, and avoiding the introduction of excess of any of the hardening elements.

The pig-iron should not contain more than 2 per cent. silicon, usually, although 2½ per cent. is often allowed, and 1½ per cent. is considered a minimum; less would cause chilling, or working too cold in the converter. Too much silicon causes rapid wear of linings by producing excessive heat and from waste of iron, and makes the product too hard when the steel retains 0.1 per cent. silicon or more.

The pig-iron should contain less than 0.1 per cent. sulphur, and less than one-half that proportion of phosphorus is desirable. Equal care should be observed in selecting fuel and flux. The purer the iron, the higher is the percentage of carbon admissible in the finished steel.

Phosphorus is never desirable; but very good ingot-iron has been made from ores and pig-iron containing a considerable amount of that element.

Many attempts have been made to produce good mild steels by dephosphorizing iron "high" in phosphorus. Of such processes, those of Heaton and of Henderson are examples. The Ponsard Furnace, with blast nozzles like Berard's, has been used with some success in such attempts, and the use of basic linings in the Bessemer converter with Holley's improvements is one of the latest methods. This latter is due to Snelus, and to Thomas and Gilchrist, the former using the magnesian lime obtained from dolomite, and the two last-named chemists using a mixture of lime and silicate of soda; the same plan has been invented in the United States by Jacob Reese, and at about the same time and independently of the foreign experimenters.*

Jeans gives the following diagram, as prepared by Richards, to illustrate the action in such cases.†

In this case, the converter was charged with about 13,200 pounds (6,000 kilogrammes) pig-iron and about 7½ per cent. of lime, and a blast of 25 pounds per square inch (0.176 kilogramme on the square centimetre) was applied. The phosphorus, carbon, and silicon were burned out, as seen in the

* The Basic Dephosphorizing Process; *Trans. Eng'r's. Soc.*, of West. Pennsylvania, Dec. 21st, 1880.

† *Steel; its History, Manufacture, &c.*, London, 1880.

diagram, the silicon going first at the rate of about one-fourth per cent. per minute for nine minutes, and then more and more slowly until, at the end of 17½ minutes, it had practically all gone. The carbon commenced burning at the end of three minutes at the rate of one-fifth per cent. per minute, and was all gone at about the same time that the last of the silicon disappeared, at the end of the blow.

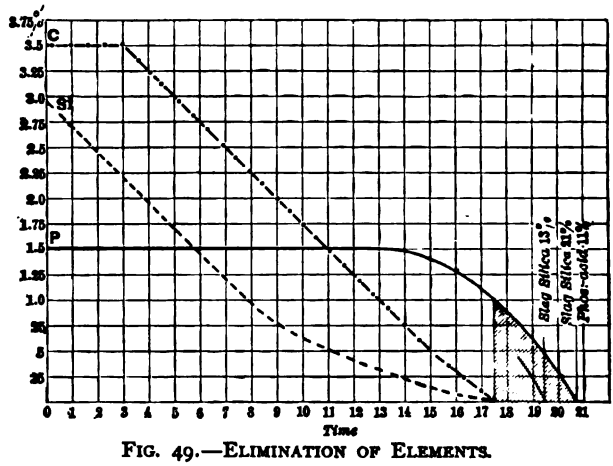


FIG. 49.—ELIMINATION OF ELEMENTS.

Six minutes from the beginning of the blow a mixture of one-third oxide of iron and two-thirds lime, to the amount of 13 per cent. of the charge, was introduced. It was only at the end of 12 minutes that the phosphorus, which amounted to 1.5 per cent. in the pig-metal, began to leave it, at first slowly then more and more rapidly, until at the end of 16 minutes it was burning at the rate of one-fourth per cent. per minute, leaving almost none at the end of the blow. This charge was overblown—*i. e.*, blown after the carbon had gone —three minutes, at the end of which period, 20½ minutes from the beginning, the phosphorus had very nearly all been removed. The rails made from this charge are said to have been of excellent quality.

Where phosphorus exists in objectionable quantity, and the attempt is thus made to remove it by the use of lime and by substitution of basic for the acid silica linings usually adopted,

these basic linings are found far less durable than the acid lining, and the necessity consequently arises for the adoption of some method of quickly and cheaply replacing them.

By the plan adopted by Holley, this requirement is met. The whole converter, *A*, is made detachable from a supporting ring, *B*, which is carried by the trunnions—as seen in the figure—which latter and the ring are left in place when the converter is taken away for relining. Meantime another converting vessel, which has been previously prepared, is put in place, and the work goes on, while the first is taken away and relined at leisure. The delay for repairs, which would ordinarily reduce the output of American works one-half, is thus avoided, and the use of iron containing a small proportion of phosphorus becomes less objectionable.

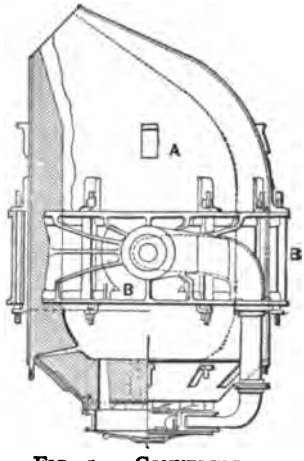


FIG. 50.—CONVERTER.

Dolomitic or magnesian limestones are used in the production of the lime, and this lime, formed into bricks, and baked, is fitted into the converter as a lining.

The cost of production is greatly reduced when, as is sometimes the case, the pig-iron is taken to the converter directly from the blast furnace. This has been done even when they are two miles or more apart.

The Quality of the Steel produced, which is primarily dependent upon the nature of the materials employed, may be improved by either or all of several chemical and physical processes.

The use of manganese is customary, in all standard methods of steel making, for the purpose of reducing the porosity of ingots; it acts by absorbing oxygen dissolved in or mechanically mixed with the molten metal, and by antagonizing the ill effects of any sulphur present. Where the metal is made very "low" in carbon, other expedients have been adopted,

as the use of silicon, which may be introduced as a silicate. This element is allowable in small proportion in ingot-iron, and if added in such quantities as to absorb all free oxygen, without combining to a serious extent with the iron, it is found to be of very decided value. The presence of minute quantities of silicon in iron intended to be forged and welded is of advantage, since it acts as an efficient flux.

Ingot-iron, containing but small quantities of carbon, may be made of good quality from ores containing moderate quantities of phosphorus, which latter element hardens the metal and strengthens it. If present in the iron with but a small total proportion of manganese and carbon, phosphorus does not seriously reduce the ductility. The proportion permissible varies for the usual applications, from 0, where the carbon is present in proportion above 0.5 per cent., to 0.25 per cent. where a minimum of carbon is present. Generally, a maximum of 0.15 per cent. is accepted. The sum of all the hardening elements is usually specified not to exceed a certain fixed amount. With iron of great purity a high percentage of carbon may be permitted without incurring danger of seriously injuring the steel by producing cold-shortness or brittleness.

Boiler-plate "steel" usually contains less than 0.25 per cent. carbon, and is properly iron; the same may be said of rail "steel," and of that used for all purposes for which iron was formerly employed.

Physical treatment, usually compression, either hot or cold, is, in some cases, practiced, for the purpose of improving the product. Capt. W. R. Jones's method of compression consists in admitting steam at high pressure into a space left above the ingot, the mould being temporarily covered by a steam-tight cap secured by a clamp. The pressure of the steam upon the molten ingot closes up all air-cells, and the thus solidified ingot is found to be homogeneous, and to possess greater strength and toughness, as well as greater density, than uncompressed ingots.

The Whitworth method consists in the subjection of the metal, while cooling and solidifying, to the pressure of a powerful hydraulic press, and the effect, as will be seen hereafter, is as satisfactory as it is remarkable.

Both of these methods of securing solidity and homogeneousness of the ingot steel are now familiar processes, and are generally considered as standard modifications of the Bessemer process. Another recent improvement consists in the use of the "soaking pit" which is simply an oven, set in the floor of the mill and lined with good fire-brick, in which the ingots may be placed as soon as cast, and there allowed to attain uniform temperature. This is an economical substitute for the reheating furnace.

The "Basic Process," by which phosphuretted ores may be used in the manufacture of good grades of steel, the processes of compression just described, and the "soaking-pit" are the most important of the later inventions in connection with Bessemer steel making.

CHAPTER VI.

CHEMICAL AND PHYSICAL PROPERTIES OF IRON AND STEEL.

Chemically and absolutely pure Iron is probably an unknown substance. Nearly pure iron is made by several methods of manufacture, or it may be deposited by electrolysis. Such metal has an exceedingly strong affinity for oxygen, sulphur, phosphorus, and some other elements, and alloys readily with many metals which are always present in its ores, or in fuel or flux, in small proportions. As it approximates to the chemically pure condition it assumes more perfectly the character of a silvery white and very lustrous metal, soft, ductile, and malleable, and, though tough, not remarkably strong; it is very heavy, its density, as deposited by electrolysis, being 8.14; is very easily oxidized; and it is an excellent conductor of heat and electricity. In consequence of its greed for oxygen, even ordinary and impure merchant iron requires to be alloyed with some silicon or other fluxing element, to make it weld easily; but, thus alloyed, it welds readily at a bright red or a white heat, at which latter temperature it is in a pasty state. Its melting point is unknown, but is higher than that of commercial wrought iron, for which the melting point is given by Pouillet at about 2,910° Fahr. (1,599° Cent.), and higher than for hard steel (2,533° Fahr., 1,389° Cent.). Alloyed with minute quantities of those elements which are usually present in its ores, it becomes harder, stronger, less ductile, and of less density, and is, for purposes of commerce and construction, thus made more valuable. The elements which almost invariably contaminate it or alloy with it are carbon, silicon, sulphur, and phosphorus in small quantities, and traces are found of aluminum, calcium, titanium, tungsten, and other metals. The

purest ores only are used in the manufacture of the best qualities of iron and steel.

The familiar grades of iron—wrought iron, steel, cast iron—vary in chemical composition from approximate purity to compounds containing 5 per cent. or more of foreign elements, principally carbon and silicon.

Commercial wrought iron of good quality contains from 0.05 per cent. of foreign elements, in the softer and purer grades, to 0.30 per cent. or more in the harder irons. Its texture is more or less fibrous if made by the processes producing weld-iron, and it often exhibits some fibre, although from a different cause, even when worked into shape from ingots. In the former case the fibre is produced by the drawing out of masses of cinder, inclosed in the sponge, into long lines of non-coherent substance, as the iron is worked under the hammer or in the rolls; in the latter case each line is the trace of an air-cell, originally of spherical form, in the ingot, but which has been similarly extended in working. The fineness and silkiness of this fibre, and the general texture of the iron, are gauges of its quality.

Magnetism is readily induced in irons, and is stronger as the iron is purer; but it is more permanent as the iron contains more carbon or other steel-making elements; and this property affords another means of determining its quality, and gives some idea of its composition.

Oxidation usually occurs less readily as the iron becomes more complex in composition; but it does not occur at ordinary temperatures, even with the best wrought iron, except in the presence of both carbonic acid and moisture; rust once appearing on polished surfaces, accelerates oxidation.

The scales of oxide formed on iron when highly heated differ in composition and physical character from the rust formed under more usual conditions; it is magnetic, while rust is the peroxide of iron. The former is extremely hard, smooth, bluish-black in color, and is elastic and durable.

The Influence of the Elements found in iron and steel is determined, not only by their own character, but, as has already been stated, by their mutual interactions.

Carbon is the most important of all these substances. When added to pure iron, it hardens and strengthens, while reducing ductility and ultimate resilience. It also, in a proportion exceeding about one-half per cent. (or less, in presence of other hardening elements), confers upon the steel the property of hardening when suddenly cooled, and of regaining its original softness by slow reduction of temperature from red heat—in other words, the property of "taking a temper." Below this limit, as in "boiler steels," wrongly so called, containing 0.20 to 0.15 per cent. carbon, the metal should soften when suddenly cooled, and this fact furnishes a "test" for such metal. Between ½ per cent, or something above, and 1¾ to 2 per cent. carbon, the quality of the steel varies from that of the softest of the "mild" steels, to the hardest of the tool-steels; passing the upper limit, the metal becomes too unmanageable and brittle for use even in the harder kinds of tools. Through this whole range the metal is capable of being forged, and can sometimes be welded even when containing as much as one per cent. carbon. The presence of silicon renders welding less difficult. Iron alloyed with over two per cent. carbon is rarely made in the refined state; all such metal is found in the market in the state of cast iron, which contains all those elements which crude iron brings with it from the ore, and from fluxes and fuels used in its reduction. Throughout the whole series, the amount of manganese, silicon, phosphorus and other "hardening elements" present, have an important influence in determining the character of the steel, and the effect of carbon as well.

The steels in the market are usually distinguished from the irons, malleable and cast, by their freedom from phosphorus, and the completeness with which they have been refined, as well as by the proportion of carbon contained in them.

The cast irons grow harder with increase in the proportion of *combined* carbon; but, passing a certain limit, they begin to exhibit the influence of graphitic carbon, and become softer and weaker, until, when containing five or six per cent. carbon, one-half of which is often in the graph-

itic state, they become very soft and easily cut, of low density, and of little strength.

The value of steel in the market approaches a maximum as it approximates to 0.8 or 1 per cent. carbon, with freedom from any other elements except manganese and silicon, which should be present in very small quantities.

Manganese hardens iron and steel, and, at the same time, usually diminishes its malleability and ductility to a less extent than does carbon. If, however, but little carbon is present, the effect of manganese is quite similar to that of carbon alone, and a steel can be made of very great tenacity, combined with great ductility and resilience. Its effect on metallic iron, in presence of other elements, is not fully determined. It is even considered by some chemists as simply an antidote to the other more injurious elements present, as sulphur and oxygen, while it is itself a lesser evil. It has usually been found that iron ores containing manganese make excellent steel.

This element is of value when the steel is to be forged or welded, and in the various processes of steel making, as a preventive of the formation of oxides that would impede in the former case, and by preventing that porosity which steel cast in ingots would always exhibit, in consequence of their absorption of oxygen, if manganese were absent. Manganese is very effective as a preventive of the hot shortness caused by sulphur, which latter element it counteracts very completely when present in the crude steel in moderate amount. Ingot-iron and steel low in carbon, and especially very low in phosphorus, is increased in strength and ductility also, by the addition of small doses of manganese, and the degree of hardening on tempering the steels is increased by its presence. Steel containing considerable carbon may take up nearly 1 per cent. manganese, if otherwise pure, and yet lose little ductility, while gaining considerably in tenacity and in tempering quality.

Mushet, one of the oldest and best authorities, considers that manganese should only be added as an antidote to sulphur, silicon, and oxygen, and that all these elements, as well as phosphorus, should be kept out of the steel to the utmost

possible extent. In this opinion, Siemens and other later authorities agree, and all unite in stating that toughness can best be secured by insuring purity of metal, whether iron or steel. Recent practice does not, however, follow this view, as the manufacture of a "manganese steel," containing little carbon, has become a well-established branch of steel making. Its presence in spring-steel has been found objectionable.

Phosphorus is the most injurious of all the elements which usually contaminate iron and steel. It confers hardness; but that quality can be far more satisfactorily obtained when desired, by the addition of other elements. It greatly reduces ductility, and causes a serious degree of cold-shortness in both iron and steel; even in foundry grades of cast iron it should usually not be admitted in higher proportion than ½ per cent., except when fluidity is desired even at the expense of considerable loss of strength. Cast-iron containing phosphorus is peculiarly liable to break under shock, and the same is true of wrought iron and steel in which it may exist in measurable amount, unless it be the only hardening element present in any notable quantity. Good tool steel should not contain more than 0.010 or 0.015 per-cent., but ingot-iron and mild steel may contain, if otherwise pure, as much as 0.1 per cent., which amount has actually been found in some spring-steel.

When nearly free from all other hardening elements, iron sometimes contains 0.35 to 0.40 per cent. phosphorus, and yet exhibits fair quality.

The effect of this element is to increase elasticity, to elevate the elastic limit, and to increase slightly the modulus of elasticity.

Wedding exhibits the method of variation of the maximum allowable percentage of phosphorus in iron and steel, varying in proportion of carbon, by a curve shown in full line in the figure. One-fourth the proportions thus given, as exhibited by the dotted curve, *T*, introduced by the Author, may be taken as the usual limit for metals of good reputation in our markets. Some few cast irons, having a reputation for fluidity when melted, contain higher propor-

tions. Wade's experiments on metal for ordnance indicate ½ per cent. phosphorus to be the maximum allowable, and ¼ per cent. to be a usual proportion in such cast iron as is used for guns; such iron contains about 3 per cent. carbon.

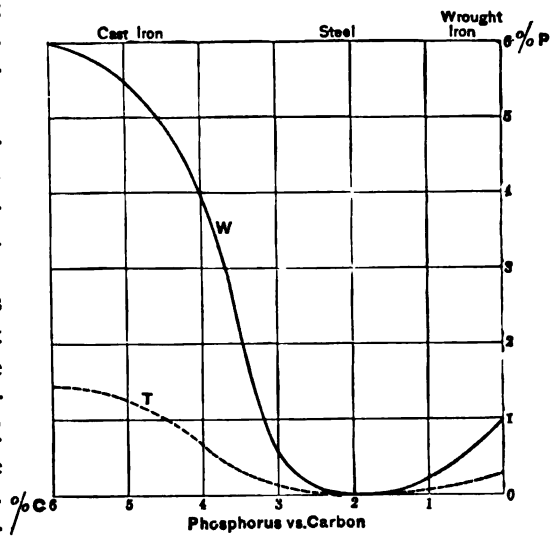


FIG. 51.

Sulphur causes brittleness at high temperatures in all grades of iron and steel. Its effect is most marked in the absence of other impurities, and it is therefore most objectionable in the finer grades of tool steel, and in iron or mild steel, which is to be welded. Its antidote is manganese, which greatly reduces its ill effect. Iron and steel containing 0.2 per cent. are not easily welded, and this figure may be taken as the extreme maximum allowable in any malleable iron or steel.

When bar-iron, containing a considerable amount of sulphur, is converted into steel by the method of cementation, a considerable amount of that element may be eliminated as bisulphide of carbon, and the steel made may be of fair quality. Using iron of a good degree of purity, the steel becomes almost perfectly free from sulphur, and particularly is this the case where manganese is present. Since the effect of sulphur is to produce hot-shortness only, its presence in moderate quantity is not objectionable in either iron or steel castings. It is stated by some authorities that iron and steel castings are stronger and tougher when containing sulphur, and it has even been added in making iron castings, both for

this reason and because it gives greater fluidity to the molten metal; ordnance iron has sometimes been thus treated.

Sulphur is eliminated to some extent in the Bessemer converter when the basic process is adopted.

Silicon is a hardening element, and its influence is the greater as the metal is otherwise purer. In weld-iron and in soft steels it is of value in small quantity where the metal is to be welded, either in the process of manufacture or in subsequent forging. In the various processes of making ingot-steel it is of use, like manganese, as a preventive of injury by oxidation, or by the formation of air-cells and production of porous ingots, and, consequently, of non-homogeneous blooms, bars, or rails. In the pneumatic process its presence has been seen to be of direct advantage in supplying fuel needed to elevate the temperature of the molten mass in the converter to a higher point than could be obtained by combustion of carbon alone. It is of further use, in some cases, if added after the blow, as it gives a sound ingot and a weldable steel. One-twentieth of one per cent. is said to be sufficient to produce a decided beneficial effect in this latter case.

In its hardening power silicon resembles carbon, which element it may replace to a limited extent. Good irons and steels usually contain from 0.10 to 0.25 per cent. of silicon; while cases are reported in which, in the absence of other hardening elements, between one and two per cent. of silicon has been found in iron of apparently good quality.

Bessemer cast irons are expected to contain from 2 to 2½ per cent. silicon, but foundry irons should contain very little; when the latter contain an excess they become weak, brittle, and peculiarly liable to crack in large castings; this latter defect is exaggerated by the presence of phosphorus. Two per cent. may be taken as the usual limit for silicon in cast iron, one-half per cent. for the steels, and one-fourth or one-fifth per cent. for good wrought irons.

Nitrogen is said by many chemists to be invariably a constituent of all grades of metal which exhibit steel-like properties, and it is by some considered an essential constituent; it has been found in all grades of both iron and steel in propor-

tions varying from 0.01 to 0.20 per cent., the usual proportion being about 0.05 per cent.

All methods of steel-making include the exposure of the iron used to the action of nitrogenous compounds or of nitrogen in the gaseous condition; but the element has been found in wrought iron in higher proportion than in steel, and it seems not to be, in itself, a steel-making element.

All the familiar metals have been alloyed with iron, but the resulting product has in no case become commercially introduced. Nickel has been alloyed with iron, and iron has been added to bronze and to brass; in each case the alloy has exhibited some peculiar properties, but has not come into general use.

So-called titanium and silicon steels have been made; but analysis has not shown them to contain either metal in any notable quantity, and such peculiar qualities as they may have exhibited have been supposed to be due to the presence of other elements.

Tin alloys freely with iron, but no use has been made of the product. Nickel and cobalt alloy with iron and steel, giving them a whiteness and lustre, and without seriously impairing ductility when added in small doses. Gold and platinum will unite with iron and steel, and the latter was found by Faraday to add strength and to give fineness of grain when not exceeding in amount one per cent. of the whole. Antimony injures iron by making it brittle and difficult to work.

Copper has been found by the Author to strengthen and toughen steel, when added in very small quantity, and Tredgold* states that it has a similar effect upon cast iron.

Wrought iron containing some tenths per cent. of copper, is red-short; in some of the best irons from Siberia were found from 0.01 to 0.03 per cent. of copper, and in some specimens of steel 0.2 per cent.; this steel was not brittle, and had been used with success for manufacturing steel axles. The presence of copper was noted in several specimens of cast iron coming

* Tredgold on Cast Iron.

from blast-furnaces of the South Oural mountains. These specimens, when examined and analyzed, showed that the presence of copper in cast iron may amount to a higher percentage than in steel or iron without injuring the quality of the metal. The specimen examined was used for castings; it filled up the moulds well, and had a fine appearance; when freshly cut it had a dark-gray color. Under the microscope small grains of copper were easily seen in the mass of the metal. This cast iron had the following average composition:*

	Per Cent.
Iron	83.514
Copper	8.123
Tin	1.252
Cobalt	0.501
Silicium	0.952
Tungsten	0.125
Carbon	3.001
Manganese	2.312
	99.780

The case illustrates well both the variety and extent to which other elements may enter into union with iron.

The Chemical Composition of the various classes of iron and steel has already been indicated as determining their nomenclature and uses. Beginning with the most impure of the cast irons and passing through the several grades of cast iron, steel, and malleable or wrought iron, it has been seen that their qualities and their applications are generally determined primarily by the proportions of carbon present, and secondarily by the effect of sulphur, phosphorus, chromium, manganese, silicon, and the other less usual ingredients which give them peculiar characteristics.

Of the Cast Irons, "No. 1 Foundry Iron" is the softest grade, is richest in carbon, and is the darkest in color of all the irons; it is weak, moderately tough, of low density, and is quite fluid when molten. It is used principally for mixing with harder grades or for purposes which compel repeated or

* *Chem. News.*

prolonged fusion. It is the most expensive of all grades of cast iron. It is to a very slight extent malleable, ductile, and somewhat flexible, is very easily worked by the file and by cutting tools. Its fracture is bright and granular, and of a bluish-gray color. Its texture is finer and more close-grained as its color is lighter. When melted it has much more fluidity than the lighter grades, flows smoothly, and fills the moulds well, taking a good impression from the minutest lines of the mould, and rarely causes trouble by "cold shuts" or "blow-holes." The best qualities have a medium fineness and closeness of texture; a clear, dark-gray color; a clean, brilliant fracture, with sharp edges; and a density that is not far from 7.2. Coarseness of grain, a dull color, and irregular structure, indicate an inferior iron. When annealed, gray cast iron is softened, weakened, and reduced in density.

"No. 2 Foundry Iron" contains less carbon than No. 1, is harder, stronger and denser, and has a finer, closer grain; it is of more frequent use than either of the other foundry grades, and is the iron most called for in all ordinary kinds of work. Its specific gravity is about 7.3.

"No. 3 Foundry Iron" is still lower in carbon, is whiter, stronger, denser, and finer in grain. It is too hard and brittle for general use, and is purchased to mix with softer irons. It often has a slightly mottled surface of fracture.

The Forge Irons are numbered 4, 5, and 6 by many makers; of these the first is often called "Bright Iron," the second "Mottled," and the third "White." White iron is very hard and brittle, but strong and dense, attaining a specific gravity of 7.5 or more. It cannot be easily filed, but takes a very high polish if ground. Its fracture is clean, bright, and silvery white, usually granular, but sometimes plainly crystalline. It burns with bright scintillation at the melting temperature. Annealing reduces its density, but increases its strength.

The forge irons are generally converted into wrought irons by the puddling process. The rich gray irons containing silicon are converted by the pneumatic method. The carbon

contained in white iron is all combined, as it is in steel; that in the gray irons is, to a considerable extent, graphitic.

The appearance of the fracture and the physical qualities of the darker grades of iron are considerably modified by variations in the size of the castings made of them, and in the rate of cooling. A large casting cooling slowly retains much of its carbon in the graphitic condition, while a small piece rapidly cooled will become whiter, and will exhibit a "chill," produced by more complete combination of its carbon with the iron. This change affects the superficial portions of iron cast in contact with "chills," or masses of iron set in the mould for the purpose, to an extent which is determined by the grade of the iron and by the amount of silicon and carbon present. For example, a well known brand of "chilling iron" is thus numbered:

No. 1.—Soft; does not chill.
No. 2.—Harder; does not chill.
No. 3.—Still harder; does not chill.
No. 3½.—Just shows a chill on the surface.
No. 4.—Chills to the depth of ½ to ¾ inch.
No. 4½.—Chills to the depth of 1 to 2 inches.
No. 5.—Mottled iron.
No. 6.—White iron, "all chill."

The depth of chill is determined in each grade by the facility with which the carbon may be changed from the graphitic to the combined state.

Analyses of the several Grades of Cast Iron have been made in great numbers and with extreme accuracy. Examples of good foundry irons are the following, made from magnetic ores:

Carbon	4.81	3.94
Silicon	1.18	2 43
Sulphur	trace	0.04
Phosphorus	0.12	0.04
Manganese	0.99	0.11
Iron and loss	92.90	93.44
	100.00	100.00

Of irons made from red hematite, Abel* gives the following:

ELEMENTS.	1.	2.	3.	4.
Carbon, combined.....	0.	trace	trace	0.35
Carbon, graphitic.....	3.22	2.24	2.30	1.86
Silicon.....	3.02	2.77	2.72	2.63
Sulphur.....	0.	0.01	0.05	0.10
Phosphorus.....	0.06	0.05	0.05	0.03
Manganese.....	0.11	0.07	trace	0.07
Arsenic.....	trace	trace	trace	trace
Copper.....	trace	trace	trace	trace

Cold and Hot Blast Irons differ considerably in quality, and this difference is so marked and so generally well understood that the market prices of iron made by the two methods differ greatly.

The higher temperature of furnaces having a hot blast causes a more complete deoxidation of the ores and the reduction of elements which are less readily deoxidized at the lower temperatures of cold-blast furnaces. The effect of heating the blast is, therefore, to cause loss of quality by increasing the proportion of deleterious elements reduced, and which combine with the iron, while greatly increasing the yield of the furnace, and decreasing the cost of fuel. When the finest quality of iron is demanded, pure ores, fuel free from sulphur and phosphorus, and flux equally pure, must be used. Hence "Cold Blast Charcoal Iron" is demanded in many cases, to the exclusion of other grades.

It has been stated by some writers that the amount of phosphorus is greater in hot than in cold-blast iron. This is considered by Percy and other chemists, and by experienced furnace-men a mistake, as it is found that all phosphorus goes into the iron in any case.

Charcoal, Coke, and Anthracite Irons differ in value for the same reason that cold-blast and hot-blast irons differ. Coal, as mined, usually contains some impurities, and some kinds of bituminous coal are very seriously contaminated by sulphur. Anthracite, used as fuel in the blast furnace, while cheap in certain localities, and convenient to handle, and while giving intense heat, has some objectionable

* "Cast Iron Experiments."

qualities; the "anthracite irons" are, therefore, often found to be of unsatisfactory character. Bituminous coals are sometimes used "raw" in the furnace, and the "raw coal iron" thus made is often very hot-short, in consequence of the presence of an excessive amount of sulphur. To secure immunity from this injury, the bituminous coals are usually coked, and the iron made with coke is, usually, if the flux is free from phosphorus, of good quality. Charcoal has the least proportion of injurious elements of all the fuels used in making iron in the blast furnace, and the charcoal irons are, therefore, of better quality, other things being equal, than the other kinds of cast iron. Charcoal furnaces are also usually small, as this fuel is too weak to carry a heavy burden, and the temperature attained within them is less likely to become excessive. They are usually supplied with a blast that is either cold or very moderately warmed—a circumstance which aids in securing excellence of quality of product.

The Chemical Change produced by Puddling, and usually in the manufacture of either weld or ingot iron, has been described as a removal of the impurities contained in cast iron, the principal of which are carbon and silicon. This process is traced by Dr. Hartmann* in a series of analyses which are, in part, given below.

Beginning with a fair quality of No. 3 cold-blast gray pig-iron made with coke, and having the composition:

12 M.	FIRST ANALYSIS. Per cent.	SECOND ANALYSIS. Per cent.	AVERAGE. Per cent.
Carbon	2.320	2.230	2.274
Silicon	2 770	2.670	2.720
Phosphorus	0.580	0.710	0.645
Sulphur	0.318	0.228	0.302
Manganese and Aluminum	traces	traces	traces
Iron	94.059	94.059	94.059
Total	100.047	99.957	100.

* Waltz und Puddle Meister.

The charge of 200 pounds (100 kilogrammes) became fully melted in forty minutes. The silicon had already begun to burn out very rapidly, and the carbon had remained unchanged. One hour from the time of charging the sample taken out contained

	Carbon.	Silicon.
Original pig	2.274	2.720
First sample, 12.40 P.M.	2.726	0.915
Second sample, 1.00 P.M.	2.905	0.197

The carbon had increased 0.629, whilst the silicon had diminished over 90 per cent.

A second sample contained

1 P.M.	First Analysis.	Second Analysis.	Average.
Carbon	2.910	2.900	2.905
Silicon	0.226	0.168	0.197

The first differed from No. 1 in being slightly malleable when hot, whilst No. 1 was brittle. The cinder remained after cooling on the surface, and not mixed with the metallic iron, as in the second analysis of sample No. 3, which was taken out five minutes later.

Boiling soon commenced, and the sample next analyzed contained a considerable amount of cinder, which was with difficulty removed. It contained

1.10 P.M.	First Analysis.	Second Analysis.	Average.
Carbon	2.468	2.421	2.444
Silicon	0.188	0.200	0.194

This sample consisted largely of minute globular grains adhering to each other and to the slag with which they were mingled with a strong glutinous adhesion, even when very hot. The grains were black, lustrous, and very brittle.

Eighty minutes from the beginning, a sample taken out for analysis somewhat resembled the last. While cooling it, little jets of blue flame were seen to burst out from it. The grains were finer than before, and their coherence was so slight that the mass was easily broken up. Their color was a lustrous black, their fracture silvery white, and the metal

was as brittle as glass. The carbon and silicon contained were as below:

1.20 P.M.	First Analysis.	Second Analysis.	Average.
Carbon.....	2.335	2.376	2.355
Silicon.....	0.187	0.178	0.182

The boiling was in full operation when the above sample was taken, the heat had been reduced, and the puddler was working the bath with his rabble. The molten mass had swollen to four times its original volume. The silicon was still passing off, and the carbon had become somewhat reduced in amount.

At 1.35 P.M., ninety-five minutes from the beginning, boiling ceased, and the mass began to shrink in volume. The carbon had ceased to burn rapidly, and the bubbling carbon monoxide no longer puffed up the semi-fluid iron. The damper had been nearly closed, the flame had become strongly charged with smoke, and the puddler had begun to "ball up" the sponge.

The sample now taken contained:

1.35 P.M.	First Analysis.	Second Analysis.	Average.
Carbon.....	1.614	1.681	1.647
Silicon.....	0.188	0.178	0.185

It had lost a large amount of carbon since the preceding sample was taken, but the silicon had been but slightly changed. The sample was somewhat malleable, and could be beaten flat and smooth by the hammer.

In five minutes more a sample taken out gave:

1.40 P.M.	First Analysis.	Second Analysis.	Average.
Carbon.....	1.253	1.160	1.206
Silicon.....	0.167	0.160	0.163

In this case the appearance was similar to the last. Blue flames of carbonic oxide appeared while it was cooling; its grains had increased in size and could be welded together. The slag was more easily separated than before. Just at this time the mass in the furnace was divided, the metal being

separated from the great mass of cinder by the puddler, as he made up his ball.

A sample taken out at 1.45, after 105 minutes' working, contained still larger grains, and analysis showed the rapid loss of carbon, already noted, to be still going on. The grains were decidedly more malleable than before. This contained:

1.45 P.M.	First Analysis.	Second Analysis.	Average.
Carbon.....	1.009	0.927	0.963
Silicon.....	0.160	0.167	0.163

Five minutes later the metal contained:

1:50 P.M.	First Analysis.	Second Analysis.	Average.
Carbon.....	0.771	0.773	0.772
Silicon.....	0.170	0.167	0.168

The grains were still larger, more coherent, and more malleable and tenacious. Each grain was coated with slag, and was thus perfectly protected against oxidation, as was shown by the fact that portions of the sample remained in the laboratory unoxidized many months.

The puddle-ball was next hammered, and rolled into a bar, which was found to contain:

	First Analysis.	Second Analysis.	Average.
Carbon.....	0.291	0.301	0.296
Silicon.....	0.130	0.110	0.120
Sulphur.....	0.132	0.126	0.134
Phosphorus.....	0.139	....	0.139

The puddle bar was cut and piled, and was rolled into wire-iron, which was found to contain:

	First Analysis.	Second Analysis.	Average.
Carbon.....	0.100	0.122	0.111
Silicon.....	0.095	0.082	0.088
Sulphur.....	0.093	0.096	0.094
Phosphorus.....	0.117	....	0.117

All four elements, sulphur, phosphorus, silicon, and carbon, are seen to have been reduced to a minimum, which is, in each case, not far from one-tenth of one per cent. Here,

as in the basic pneumatic process, the phosphorus is evidently the last to go; but it does begin to pass out at the end of the puddling process after the burning out of the other elements has nearly ceased, and its reduction continues—even during the process of working the sponge, and of making the bloom and the bar.

Collating all these analyses, we have:

SAMPLE.	TIME P.M.	CARBON.	SILICON.
Original pig	....	2.275	2.720
No. 1	12.40	2.726	0.915
No. 2	1.00	2.905	0.197
No. 3	1.5	2.444	0.194
No. 4	1.20	2.305	0.182
No. 5	1.35	1.647	0.183
No. 6	1.40	1.206	0.163
No. 7	1.45	0.963	0.163
No. 8	1.50	0.772	0.168
Puddle bar	....	0.296	0.120
Wire-iron	....	0.111	0.088

Comparing these results with the account already given of the pneumatic process, it is seen that the order of operations and the method of removal o foreign elements is precisely the same in both. The silicon starts first, and immediately on subjecting the molten pig-iron to the oxygen of the air; after the silicon has nearly reached a minimum, the carbon rapidly passes out, and it is only when both are nearly gone that phosphorus begins to pass off; dephosphorization is a process which only goes on when no other oxidizable metalloids are present. The slag remaining in the furnace, after the withdrawal of the balls, had the following constitution:

Silicic acid	16.53
Protoxide of iron	66.23
Sulphide of iron	6.80
Phosphoric acid	3.80
Protoxide of manganese	4.90
Alumina	1.04
Lime	0.70
Total	100.00

Thus the slag contains nearly all the impurities of the original pig metal, as was remarked in an earlier chapter.

Finished Malleable, or Weld-iron, as made by puddling in the instance above cited, has been seen to have been a composition, which, allowing ½ per cent. for cinder and other undetermined constituents, contained:

Carbon	0.111
Silicon	0.088
Sulphur	0.094
Phosphorus	0.117
Slag, etc	0.500
Iron by difference	99.090
Total	100.000

Swedish iron of fine "J. B." quality, which is a good standard for comparison, has a composition, according to Percy, of

Carbon	0.087
Silicon	0.056
Sulphur	0.005
Arsenic	trace
Iron	99.220

Copper is said by Eggertz to be present in some Swedish iron to the extent of 0.03 per cent.

Lowmoor iron, made for armor-plate, is reported by Percy as containing:

Carbon	0.016.
Silicon	0.122
Sulphur	0.104
Phosphorus	0.106
Manganese	0.280

with traces of cobalt and nickel. It has a specific gravity of 7.8, and a tenacity of 55,202 pounds per square inch (3,881 kilogs. per square centimetre).

A remarkably pure sample of Bowling iron was reported*

* *Appleton's Chemical Journal*, 1873, p. 15.

as made from a pig, of which the analysis accompanies that of the wrought iron made from it thus:

	PIG.	BAR.
Carbon, combined	0.581	0.272
" graphitic	3.155	
Silicon	1.346	0.000
Sulphur	0.070	trace
Phosphorus	0.635	0.000
Manganese	1.472	0.000
Iron by difference	92.741	99.798
Total	100.000	100.000

This is the purest iron made, commercially, of which the Author has record.

These are all extraordinarily good irons, and are such as are made by but few makers of weld-iron either in the United States or in Europe.

The following analyses made by Blair,* of four samples of the purest irons supplied in the market for chain-iron, are of value as illustrative of the character of the best weld-irons made for general use, and of very good iron (two each).

MARK.	*O*, 1¾"	*L*, 1½"	*Px*, 1¾"	*K*, 1½"	*D*, 1½"
Carbon, combined	0.033	0.429	0.057	0.069	0.024
Carbon, graphitic	0.009	0.024	0.009	0.010	
Silicon	0.073	0.105	0.020	0.159	0.108
Sulphur	0.004	trace	0.001	0.004	0.005
Phosphorus	0.078	0.065	0.075	0.161	0.158
Manganese	0.005	0.006	0.009	0.026	0.038
Copper	0.046	0.008	0.008	0.079	0.018
Cobalt	0.034	trace	0.020	0.027	0.031
Nickel	0.037	0.011	0.023	0.034	0.021
Slag	0.974	0.325	1.214	0.470	.....

Of irons of lowest grade analyzed are the following:

* *Report of U. S. Board on Tests of Iron, Steel, etc.*, pp. 247–248.

MARK.	*P*, 1″	*Y*, 1¼	*M*, 1¼	CONTRACT.
Carbon, combined	0.025	0.043	0.053	0.026
Carbon, graphitic	0.008	0.008		0.000
Silicon	0.182	0.303	0.187	0.238
Sulphur	0.009	0.003	0.011	0.046
Phosphorus	0.250	0.213	0.166	0.328
Manganese	0.033	0.007	0.012	trace
Copper	0.081	0.011	0.498	0.134
Cobalt	0.037	0.013	0.047	0.039
Nickel	0.057	0.008	0.026	0.042
Slag	0.848	1.230	0.994	0.768

Of the whole collection that sample marked *Px*, was considered best for general purposes; it is seen to have had a very small proportion of impurities, although considerable slag was mechanically mixed with it.

The iron marked *O*, had remarkable ductility, and but little tenacity. *L* was very strong, but its high percentage of carbon made it comparatively brittle, and it was difficult to weld; it is, properly, "weld-steel." *Y* was weak, brittle, and of unsatisfactory quality, in consequence of the presence of an excessive amount of silicon and of slag. *M* had an unusual proportion of copper, and was strong and moderately ductile, but it was almost impossible to weld it properly; once welded, however, the point of junction was very strong.

It was concluded from the study of the series of irons from which the above are selected, that phosphorus may be allowed in any proportion less than 0.10 per cent., and may even be of advantage where the carbon is below 0.03, and silicon less than 0.15 per cent. Silicon in excess, it is concluded, reduces strength, but loss of tenacity and ductility are oftener due to the presence of silica than to that of silicon. It was found that the same brand of iron may vary greatly in chemical constitution and physical character. With iron of fairly good composition, the quality is determined much more by differences in working, and peculiarities in method of manufacture, than by minute differences of composition such as usually exist.

Meteoric Iron is of no value to the engineer, and is of interest only as an example of native iron. A sample analyzed by Cairns contained:

Iron	81.480	Calcium	0.163
Nickel	17.173	Carbon	0.071
Cobalt	0.604	Silicon	0.032
Aluminum	0.088	Phosphorus	0.308
Chromium	0.020	Sulphur	0.012
Magnesium	0.010	Potassium	0.026
Total			99.987

Of the twelve elements quantitatively determined by this analysis, aluminum, calcium, and potassium have been rarely observed in meteoric iron—meteors free from silicates—while the absence of copper, tin, manganese and sodium, is to be noted.

The reduction of cast iron to the malleable state by the process described hereafter as *malleableizing*, has been studied by Dr. Miller, who gives the following analyses* of the cast iron used, and of the product:

Carbon; combined	2.217	0.434
Carbon; graphitic	0.583	0.431
Silicon	0.931	0.409
Aluminum	trace	trace
Sulphur	0.015	0.000
Phosphorus	trace	trace
Sand	0.502	

Carbon, in the combined state, was greatly reduced, while the graphitic carbon remained little changed. The silicon was reduced one-half, and the sulphur entirely removed; this reduction of sulphur has been observed in that process of cementation also which yields cemented steel.

The Process of Cementation and production of blister-steel has been carefully studied by many chemists. Boussingault† subjected a sample of fine Swedish iron to this process, with the following results:

The cementing-boxes had a capacity of 175 cubic feet (4.9

* Percy, p. 111.

† Comptes Rendus.

cubic metres), and each held 30,000 pounds (13,630 kilogrammes) of iron, and about one-eighth that weight of the brasque, which supplied carbon to the metal. After cementation, the steel, which had then been in the box a month, including time allowed for cooling, presented a silver white fracture, and had undergone a change, which is exhibited by the accompanying table:

	Weight.	Iron.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese
Iron....	2,000 gr.	99.47	0.03	0.0106	0.0015	0.0057	0.0090
Steel ...	2,026 gr.	99.57	0.16	0.0031	0.0005	0.0066	0.0071

Crucible Steels, whether made by cementation and subsequent fusion or directly by fusion of iron in presence of carbon, have the same composition in the same grade, except that the former method eliminates impurities rather more perfectly than the latter. Steels are graded by their physical structure, as seen by the eye of the experienced steel-maker. This grading is done with wonderful exactness, and the grades so established are usually in precisely the order of their proportion of carbon. Analyses, made by Langley for Mr. Metcalf, of a set of eight samples selected for analysis, and for tests of their strength by the Author, gave the following composition:

COMPOSITION OF STEELS.

NO.	IRON BY DIFFERENCE	DIFFERENCE.	CARBON.	DIFFERENCE.	SILICON.	PHOSPHORUS.	SULPHUR.	MANGANESE.	REMARKS.
1	99.554	....	.404	....	.029	.022	trace	Undetermined.	Maximum errors.
2	99.325	.129	.599	.195	.039	.035	.00 002		Silicon..... .00 002
3	99.143	.182	.789	.190	.026	.040	.00 002		Phosphorus...00 01
4	99.062	.081	.856	.067	.023	.056	.00 003		Carbon ..... .00 03
5	98.965	.097	.867	.011	.126	.040	.00 000		
6	98.801	.164	.939	.073	.205	.037	.00 000	.00 018	DIFFERENCES.
7	98.745	.056	1.036	.097	.181	.029	.00 000	.00 009	
8	98.673	.072	1.166	.130	.138	.019	.00 004	Undetermined.	Max. Min.
Mean differences.		.0976	.....	0.952					Iron..... .282 .056
									Carbon.. .195 .011

A year afterward, the same steel-maker selected twelve samples in similar order with the following result (Fig. 52):

Below are diagrams, showing the relations of the different elements in these two series. The break in the column of differences of iron in table on page 191, is due to the abnormal amount of silicon in No. 6, from, doubtless, some accident in taking the drillings.

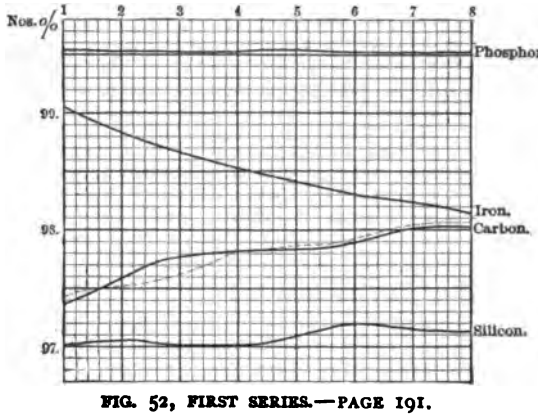


FIG. 52, FIRST SERIES.—PAGE 191.

The dotted line in the first diagram shows the carbon of the second series. The vertical scale is one-tenth per cent. to each division.

It is seen that the carbon is the only element which follows the change of grades; the other elements are almost invariable in all samples.

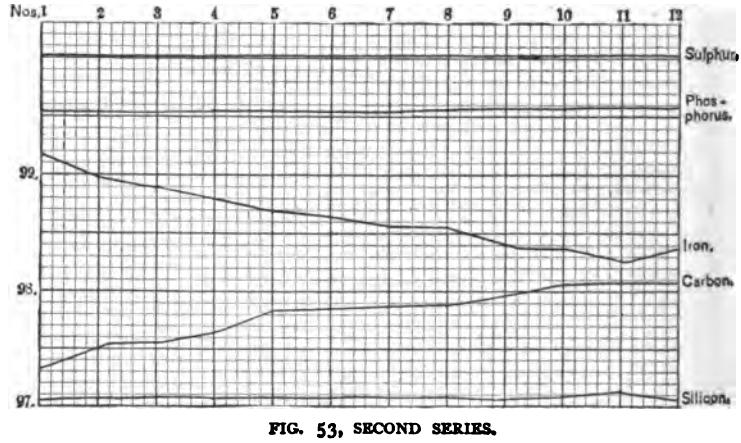


FIG. 53, SECOND SERIES.

Of all these steels, the only example of a "mild steel" is No. 1, in the first series, and Nos. 1, 2, and 3, in the second.

The higher numbers are tool-steels, and the intermediate grades are machinery steels, although of good composition for soft tools. It is evident that, where the steel is known to be made from pure material, the engineer may rely either upon tests made by an expert chemist, or upon the eye of the experienced steel-maker, in selecting the steel required for any specified purpose.

A set of steels analyzed by Blair, for the U. S. Board, as above, had the following composition:

NUMBER.	TOTAL CARBON.	SILICON.	SULPHUR.	PHOSPHORUS.	MANGANESE.	COPPER.	COBALT.	NICKEL.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	0.973	0.213	0.003	0.025	0.073	0.008	0.008	trace
2	0.886	0.196	0.002	0.037	0.185	0.006	0.018	0.021
3	0.694	0.128	trace	0.057	0.137	0.010	0.010	0.013
4	0.994	0.140	0.003	0.027	0.101	0.006	0.021	0.018
5	0.401	0.085	0.006	0.032	0.112	0.008	0.021	0.026
6	0.905	0.061	trace	0.026	0.108	0.004	0.016	0.018
7	0.915	0 191	0.002	0.026	0.086	0.002	0.018	0.013
8	0.238	0.105	0.012	0.034	0.184	0.022	0.016	0.021
9	0.463	0.121	0.002	0.020	trace	0.003	0.018	0.018
10	0.009	0.163	0.009	0.084	0.020	0.023	0.021	0.016

In this set, Nos. 3, 5, 8, 9 are mild steels, and No. 10 is an ingot iron. All are of fine quality, and have a good reputation in the market.

The steel-maker indicates the proportion of carbon contained in steel by designating its "*temper*," a term which must be carefully distinguished from the "tempering" of the tool-dresser and mechanic.

Seebohm gives the following list of useful tempers for cast steel:

Razor Temper (1½ per cent. carbon). This steel is so easily burnt by being overheated, that it can only be placed in the hands of a very skillful workman. When properly treated, it will do twice the work of ordinary tool steel for turning chilled rolls, etc.

Saw-file Temper (1⅜ per cent. carbon) requires careful treatment, and, although it will stand more fire than the preceding temper, should not be heated above a cherry red.

Tool Temper (1¼ per cent. carbon) is the most useful temper for turning tools, drills, and planing-machine tools, in the hands of ordinary workmen. It is possible to weld cast steel of this temper with care and skill.

Spindle Temper (1⅛ per cent. carbon) is a very useful temper for mill-picks, circular cutters, very large turning tools, taps, screwing dies, etc. It requires considerable care in welding.

Chisel Temper (1 per cent. carbon) is an extremely useful temper, combining great toughness in the unhardened state, with capacity of hardening at a low heat. It may also be welded without much difficulty, and is well adapted for tools where the unhardened part is required to bear the blow of a hammer without breaking but where a hard cutting edge is required, such as cold chisels, etc.

Set Temper (⅞ per cent. carbon). This temper is adapted for tools where the chief "punishment" is on the unhardened part, such as cold sets, which have to stand the blows of a very heavy hammer.

Die Temper (¾ per cent. carbon) is the most suitable temper for tools, where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, boiler-cups, etc. Both the last two tempers may be easily welded by a mechanic accustomed to weld cast steel.*

The Pneumatic and Open-Hearth Processes are usually employed only in the manufacture of soft steels and ingot-irons; the latter is by far the most useful product.

A report to the Iron Office in Sweden contains the following analyses of Bessemer steels:†

Nos. 1 to 5 grade up from the softest ingot-iron to rather hard tool-steel; their analyses indicate excellent quality; they are "low" in phosphorus, free from sulphur, contain a little silicon, and a fair amount of manganese.

* Die-makers in the United States use the harder steels for much of their work.

† *Metallurgical Review*, 1877.

	C.	Si.	Mn.	P.	S.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1. Steel made from the blast furnace without addition of spiegeleisen, at Westanfors, Sweden	0.085	0.008	trace	0.025	trace
2. " " " " " "	0.300	0.044	0.179	0.033	trace
3. " " " " " "	0.700	0.032	0.256	.....	trace
4. " " " " " "	0.950	0.047	0.463	0.032	trace
5. " " " " " "	1.050	0.067	0.355	.....	trace
6. Barrow-in-Furness—For coarse wire	0.200	0.179	0.214	0.086	0.030
7. Germany—For rail heads	0.138	0.306	0.386	0.034	0.040
8. " —For rails (from iron poor in manganese)	0.150	0.091	0.264	0.032	0.025
9. " —For rails (from mixture of Workington hematite and German manganiferous pig)	0.046	0.634	0.638	0.093	0.045
10. Neuberg—For boiler plate direct from the blast furnace	0.250	0.016	0.136	.....	0.010
11. " —Iron first remelted in cupola	0.300	0.056	0.273	0.041	0.040

Barrow ingot-iron, No. 6, is of acknowledged excellence, and the same may be said of the German and Austrian ingot-irons, which conclude the list.

Kerpeley gives the following analyses of different qualities of Bessemer steel rails:

	a.	*b.*	*c.*	*d.*	*e.*
Carbon	0.082	0.126	0.313	0.314	0.218
Silicon	0.902	0.452	0.078	0.047	0.068
Slag	0.016	.....	.....	.....	.....
Phosphorus	0.042	.....	0.071	0.046	0.080
Sulphur	0.064	.....	0.076	0.046	0.035
Copper	trace	.....	trace	0.336	0.123
Manganese	1.277	0.851	0.515	0.165	0.317

Rails *a* were soft and bad, *b* were somewhat harder, while *c*, *d*, and *e* were hard, and of excellent quality. Kerpeley draws attention to the circumstance, shown by analyses *a* and *b* particularly, that manganese and silicon do not harden steel low in carbon, and that their hardening effect decreases, even if the percentage of both is high, as the quantities of both approach equality. As long as the percentage of silicon is not much more than one-half of that of manganese, the hardening effect of both is noticeable, provided the percentage of carbon does not fall below 0.15 per cent.

Rails made for the principal railroads of the U. S. are expected to contain, as maxima, Dr. Dudley's proportions:

Phosphorus	00.10
Silicon	00.04
Carbon	00.25 to 00.35
Manganese	00.30 to 00.40

The Physical Properties of Iron vary with its chemical composition, and through an immensely extended range of quality. The strength, elasticity, and ductility of iron and steel will be considered in another chapter; we have here to refer only to those more purely physical properties which are not usually considered of such direct and general importance in engineering work.

As has been seen, and as will be noted by the reader of the reports of metallurgical chemists, cast iron contains, usually, in its several grades:

	Per Cent
Carbon	2.25 to 5.5
Silicon	0.15 to 5.5
Manganese	0.00 to 3.0
Sulphur	0.00 to 1.0
Phosphorus	0.00 to 1.5

Wrought iron and steel contain from one-tenth to one-fourth these proportions. With every change in absolute, and with all changes of relative proportions of alloying substances, the physical properties of these metals undergo greater or less change, and it is only when the exact chemical constitution of the metals, and the method and extent to which they have been worked are known, that the skillful metallurgist or engineer can confidently say what is the quality of the metal, and what will be found to be its peculiarities. Conversely, knowing the character of the work to be done, and the method by which the material is to be subjected to strain, or to physical or chemical action, he can so write his specifications as to secure the metal best adapted to the proposed purpose.

Pure Iron, as has been stated, is almost unknown. Those specimens produced in the chemical laboratory by chemical reactions, or by electrolysis, are described as silver-white, very ductile and malleable, softer than any commercial iron, but breaking with either a granular or a crystalline fracture.

Its specific gravity is given at 8.13 to 8.14, and after remelting about 7.85.

Iron crystallizes in the cubical system, when subjected to long continued heat and, perhaps, to jarring. It has a fusing point at not far from 3,632° Fahr. (2,000° Cent.), and has been volatilized, according to Elsner,* at a temperature of about 5,432° Fahr. (3,000° Cent.).

Commercial Malleable or Wrought Iron (weld-iron) has a specific gravity of from 7.5 to 7.8, determined by its chemical composition and physical structure. Its specific heat is given by Regnault at 0.113795, and it is said to increase slightly with increase in carbon; it conducts heat at a rate, according to Despretz, of 0.3743, the conductivity of gold being taken as unity.

Its linear expansion may be taken at 0.0000677 per degree Fahr., or 0.00012 per degree Cent. It expands, between ordinary temperatures and a white heat, about 0.013, and about 0.008 between a red and a white heat. Its melting point is lowered, as the proportion of carbon and other foreign elements increase.

The Electric Conductivity of good iron is given at from 0.15 to 0.20, copper being 1. It is strongly affected by the magnet, and its magnetic power is reduced, but is rendered more permanent, by the addition of carbon; it loses magnetic power with increasing temperature, its magnetism vanishing at a bright red or a white heat.

The Hardness of Iron increases with the addition of carbon, manganese, chromium, or phosphorus. Pure iron is probably too soft to be of value in the arts. Its tenacity increases with the addition of hardening elements, and is reduced by elevation of temperature; after passing through the pasty, or welding temperature, it becomes liquid.

Malleability and Tenacity are usually affected in opposite ways by the addition of foreign elements to pure iron; both will vary, but not in the same ratio in all cases; carbon reduces the malleability to a less extent for a given increase

* *Les Mondes*, 1873, p. 404.

of tenacity than any other of the elements usually found in iron or steel; except, perhaps, manganese in small doses, which is said not to seriously reduce malleability. Ductility is affected in the same manner as malleability. Increase of temperature increases both the latter qualities.

With some irons, heating to a red heat and suddenly cooling in water causes hardening; but the best grades either undergo no change, or perceptibly soften when so treated. The ingot-irons—"mild steels"—are thus softened if of the quality considered best for use in boiler-plate, or for bridges and similar purposes.

The Texture of Iron varies greatly with its treatment. Ingots of either iron or steel are often of crystalline or granular structure, but both acquire a fine grain, and iron takes a silky, fibrous texture when well worked under the hammer or in the rolls. The granular and sometimes the crystalline character reappears after prolonged cold-hammering, or often after repeated heavy shocks.

Cast Iron has a specific gravity of 7.00 to 7.60, averaging 7.25 or 7.30 for the finest grades of ordnance-iron and engine castings. Good cast iron melts at about 2,732° Fahr. (1,500° Cent.), but the fusing point varies with variations of composition. White iron passes through a semi-fluid condition at the melting-point, and only flows freely at a considerably higher temperature; it is easily chilled by sudden cooling, and, when slowly cooled, usually becomes more gray as the cooling is more retarded. On the other hand, a gray iron may in some cases become nearly white on being suddenly cooled.

The specific heat of gray iron averages 0.13983, according to Regnault, and that of white iron 0.12728. Cast iron expands more than wrought iron, and the pattern makers' rule allows a "shrink" of one-eighth inch to the foot (1 centimetre per metre) in cooling from the temperature of solidification to that of the atmosphere. Rinman found the shrinkage to be 0.013 from the red heat, and 0.020 from a white heat.

Cast iron, on the whole, contracts on solidifying, but, at

the moment of solidification, a slight expansion takes place, which causes it to "set" in contact with the mould, and it thus makes good castings.

Guettier* gives the following figures for cast iron:

	S. G.	COEFF. OF EXPANSION.	
Dark Foundry Iron.....	6.80	0.001111	Roy.
Gray " "	7.20	0.001182	Dulong.
Mottled Cast "	7.35	*Specific Heat.*	
White " "	7.60	0.12893	Regnault.
Very white iron	7.80	0.1400	Pouillet.

Steel of good quality has a grayish white color, approaching in the finer grades a silver white, and has a lustre which is superior to that of the cruder sorts of wrought iron, but not to that of the finest grades; it retains its polish much better than iron. In hardness the true steels are superior to all ordinary grades of iron, but some chilled cast irons and some kinds of white iron will cut substances that resist the hardest steels. The strength of steel is greater than that of iron, and, within usual commercial limits, is the higher as the proportion of hardening elements is greater. It is of comparatively low ductility and malleability, but it can be forged, and all but the hardest grades of the tool steels can be welded by an expert workman. It becomes quite soft at a high heat, and can then be easily forged, but is liable to lose quality in the operation. Its specific gravity varies from 7.55 to 7.8. Steel melts at a higher temperature than cast iron, but less than malleable iron, and its fusion point may be taken at 3,272° Fahr. (1,800° Cent.) for tool steels, though variable with the proportion of carbon and other elements present. Its specific heat is given by Regnault as 0.11840; its extension is about 0.010 when raised to the red heat, and 0.012 at a white heat. Its electric conductivity is nearly that of iron. The magnetism of tool steel is very permanent.

Tempering is a process which gives steel any desired degree

* *L'emploi de la Fonte de Fer;* Paris, 1861.

of hardness, and the power of accepting this change of physical condition is the most valuable property of steel, and constitutes its distinguishing peculiarity. Sudden cooling from a high heat hardens, and slow cooling softens, this remarkable metal. The tool maker or tool dresser, by adopting the one or the other or both of these methods in succession, is able to secure any temper that he desires.

The hardening liquid is usually either water or oil, but solutions, as of salt in water, and other liquids, as mercury, are sometimes used. The same liquid will produce different effects at different temperatures either of the fluid or of the steel. When highly heated and plunged into cold mercury, good tool steel becomes exceedingly hard, and will cut nearly all known substances. At moderate heats the Author has found steel both strengthened and toughened by mercury also. Heated to a lower temperature and plunged into a hot oil-bath, it is not made much softer, but is greatly strengthened and toughened.

The Working of Tool-Steel involves, usually, forging, hardening and tempering, to obtain a certain well determined hardness and temper. "Hardening" is a process of sudden cooling which results in the production of so great a degree of hardness that some method of softening to the desired temper must usually be practiced, to give the tool or other piece of steel the quality or "temper" demanded. This second process is known as that of "tempering." It is sometimes possible to temper without prior hardening.

The effect of hardening is well illustrated by an experiment devised by Metcalf.*

A small bar of tool-steel is nicked deeply at intervals of three-fourths of an inch or an inch (1.9 to 2.54 centimetres) for a length of 6 or 8 inches (15 to 20 centimetres). The bar is heated in such a manner that the extremity shall be white-hot, and the heat gradually reduced along the bar until, at the other end of the nicked part, the steel is below the red heat; then, numbering the pieces, as in the illustration, from

* *Metallurgical Review*, 1877.

1 to 8, beginning at the white-hot end, No. 1 will be white-hot and scintillating; No. 2 white-hot; No. 3 bright yellow; No. 4

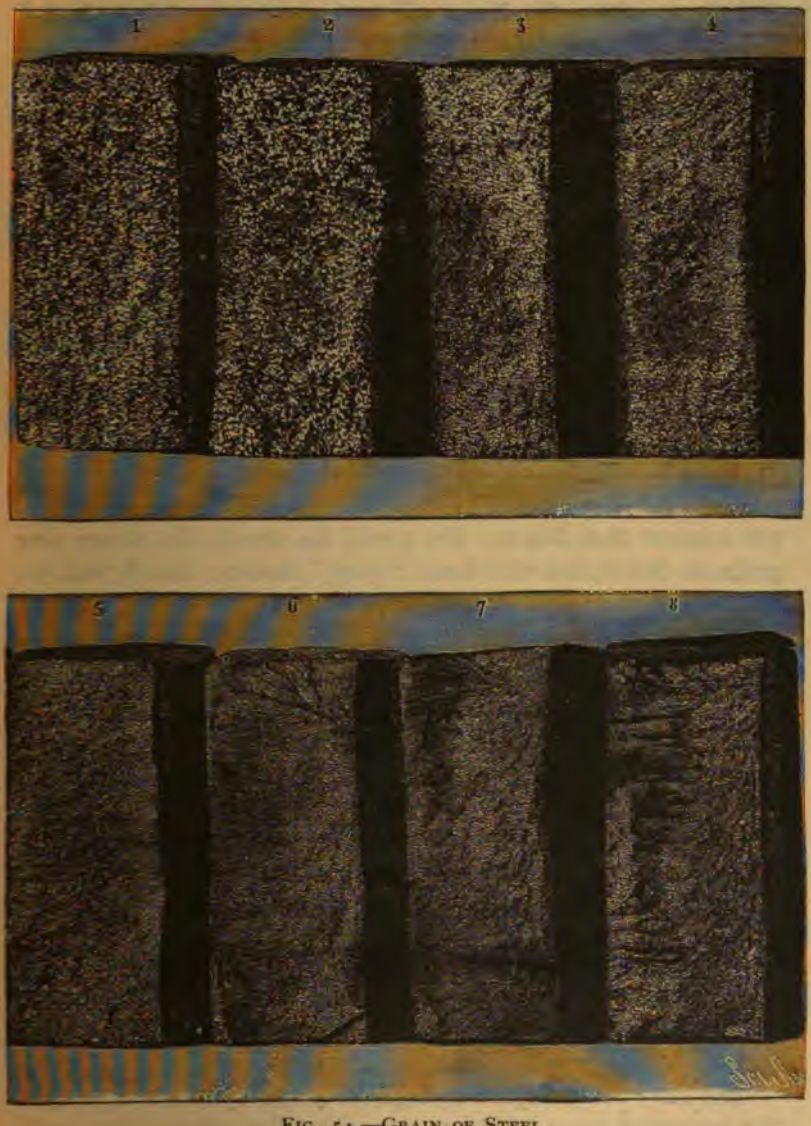


FIG. 54.—GRAIN OF STEEL.

low yellow, or orange; No. 5 bright red; No. 6 dull red; No. 7 a low red heat; and No. 8 will be a black heat. Quenching in water and cooling thoroughly, and then trying the several pieces with a file, No. 1 will be found too hard to cut, and will scratch glass; Nos. 2, 3 and 4 will be very hard; 5 and 6 quite hard enough for any ordinary tools; No. 7 hard enough to "tap steel;" and No. 8 will be unhardened, the hardening temper being, according to the observations of the Author, above 932° Fahr. (500° Cent.). Breaking up the bar, No. 1 will be found as brittle as glass or quartz; No. 2 nearly as brittle; Nos. 3, 4 and 5 each a little less brittle, and a little tougher and stronger, as the number is higher; Nos. 6 and 7 will be tough and very much stronger than No. 8 and the unheated bar, which retain all their original toughness.

In texture and color No. 1 will be coarse, yellowish, and very lustrous; No. 2 will be coarse and not quite so yellow as No. 1; No. 3 will be finer than 1 or 2, and coarser than No. 8, and will have a "fiery" lustre; No. 4, like No. 3, not quite so coarse, yet coarser than No. 8; No. 5 will be about the same size grain as No. 8, but will have "fiery" lustre; No. 6 will be much finer than No. 8, will have no "fiery" lustre, will be hard through, and very strong. This exhibits the "refining" by hardening. No. 7 will be refined and hard on the corners and edges, and rather coarser, and not quite as hard in the middle, and about the right heat for hardening taps, and milling tools, the teeth of which will be amply hard, while there will be no danger of cracking the tool. No. 8 exhibits the original grain of the bar.

A crack, as seen in No. 4, usually extends along to the refined piece, but rarely, if ever, beyond it. The investigator concludes:

(1.) Any difference in temperature sufficiently great to be seen by the color, will cause a corresponding difference in the grain. This variation in grain will produce internal strains and cracks.

(2.) Any temperature so high as to open the grain so that the hardened piece will be coarser than the original bar, will

cause the hardened piece to be brittle, and liable to crack and crumble on the edges in use.

(3.) A temperature high enough to cause a piece to harden through, but not high enough to open the grain, will cause the piece to "refine," to be stronger than the untempered bar, and to carry a tough, keen, cutting edge.

(4.) A temperature which will harden and refine the corners and edges of a bar but which will not harden the bar through, is just the right heat at which to harden taps, rose-bitts, and complicated cutters of any shape, as it will harden the teeth sufficiently without risk of cracking, and will leave the mass of the tool soft and tough, so that it can yield a little to pressure, and thus prevent the teeth tearing out. These four rules are general, and apply equally well to any quality of steel or to any temper of steel.

(5.) Steel that is so mild that it will not harden in the ordinary acceptance of the term, will show differences of grain corresponding to variations in temperature.

To restore any of the first seven pieces shown in Fig. 54 to the original structure as shown in the last, it is only necessary to heat it through to a good red heat, not to a high red, allow it to stay at this temperature for ten minutes to thirty minutes, according to the size of the piece, and then to cool slowly. If upon the first trial the restoration should be found incomplete, and the piece, upon being fractured, should still show some fiery grains, a second heating, continued a little longer than the first, would cause a restoration of structure. This property of restoration is not peculiar to any steel. A piece restored from overheating, is never quite as good as it would have remained if it had never been abused; and no occasion should ever be given for the use of this process of restoration except as an interesting experiment. The original and proper strength of fine steel can never be fully restored after it has once been destroyed by overheating.

A set of six samples treated as above were examined by Langley, and their densities compared with those of untreated bars from the same ingots. The samples were from the set

numbered 1 to 12, in page 192. The results were thus shown:*

	1	2	3	4	5	6	7	8	9	10	11	12
Ingot density	7.855	7.836	7.841	7.829	7.838	7.824	7.819	7.818	7.813	7.000	7.803	7.805
Ingot carbon	0.302	0.490	0.589	0.649	0.801	0.841	0.867	0.871	0.955	1.007	1.058	1.079
Order of samples from bar	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	...
S. G. Burned 1	.....	.....	7.818	7.792	.....	7.789	.....	7.752	.....	7.744	.....	7.690
2	.....	.....	7.814	7.811	...	7.784	.....	7.755	.....	7.749	.....	7.741
3	.....	.....	7.823	7.830	.....	7.780	.....	7.758	.....	7.755	.....	7.769
4	.....	.....	7.826	7.849	.....	7.808	...	7.773	.....	7.789	.....	7.798
5	.....	.....	7.831	7.806	.....	7.812	.....	7.790	.....	7.812	.....	7.811
Cold 6	.....	...	7.844	7.824	.....	7.829	.....	7.825	.....	7.826	.....	7.825

The density decreases in the unheated bar from 7.855 to 7.805, as the carbon increases from 0.302 to 1.079. It decreases with the increase in hardness in each sample, and the change is greatest with the steel containing most carbon; it consequently happens that hard steels are much more liable to crack and warp, or twist in hardening, than softer grades; the coefficient of expansion is also less for soft than for hard steels.

Repeated hardening, even from a very low temperature, increases still further the volume of the steel, with corresponding reduction of density.

A high heat may be permitted in working steel where hardening or tempering is not to follow, as it will forge well, unless very hard, and, if quickly handled, need not be perceptibly injured. Long exposure to a high temperature is liable to injure it by giving it a coarse grain, and by causing loss of carbon.

Steel should usually, and especially when it is to be tempered, be worked at a moderate temperature, should be very uniformly heated, and should be worked rapidly. "Soaking" in the fire may cause serious loss of quality.

The fire should be clean, heavy, and just hot enough to heat rapidly without burning or softening the edges and corners of the steel; it should have a deoxidizing flame. Welding can be best done by using melted and ground borax as a flux, and the forging should be so conducted as to refine

* *American Chemist*, Nov., 1876.

the steel, and to leave the edges and corners sharp and sound.

When hardening, a very uniform heat is required for pieces of uniform section, and higher heat is necessary as the size of its section increases; but this difference should not be great, and it should be very carefully graded, as a high heat produces a coarse, open grain, and irregularity of heating is likely to cause cracking from internal strain. Cooling should be moderately rapid, complete, and perfectly regular. The bath should be large, and supplied with running water when large pieces are to be hardened. Tempering should be done very carefully, and the cooling should take place slowly and very regularly throughout the piece. The lowest heat at which the steel will harden is best. Hot steel, if not intended to be tempered, should always be cooled slowly, and in a dry place of uniform temperature. When annealing, heating slowly to a low heat, and cooling in ashes or other non-conducting material, gives the best results.

Pieces of very small section are sometimes tempered by contact with a smooth surface of cold metal; they may be annealed by cooling slowly in contact with, and simultaneously with, a larger mass of heated iron. Charcoal is the best fuel for use in working steel, and coke is better than coal.

To prevent loss of carbon, small articles are often covered with a flux having carbonizing or deoxidizing properties. Watch-springs are sometimes heated in molten glass, and larger articles in a bath of melted metal, as lead.

In Drawing the Temper, the hardened steel is usually reheated until the scale of oxide on the surface assumes a certain color; which color indicates a certain temperature which is constant, or nearly so, for any one steel, and is slightly different for different steels. The colors and the tempers so obtained are usually given as on page 206.

According to De Bonneville,* in hardening springs, those of light wire, or long in proportion to their diameter, should be placed on a mandrel fitting loosely, and heated while on

* *Van Nostrand's Magazine*, 1878; p. 391, *et seq.*

TEMPERATURE.		COLOR.	USE.
Cent.	Fahr.		
220°	428°	Pale yellow.	Surgical instruments.
230	446	Straw.	Penknives, razors ; wood-tools.
255	491	Brown-yellow.	Chisels and scissors.
265	509	Purplish.	Axes ; heavy knives.
275	527	Purple.	Table knives ; springs.
290	534	Pale blue.	Watch-springs ; swords.
295	563	Dark blue.	Fine saws, drills.
315	600	Very dark blue.	Hand-saws.
350	662	Very dark blue, verging on green.	Too soft for any ordinary tools.

it to prevent bending and disarrangement of the coils during the heating process. The fire should be clear, of green coal; sometimes a fire is built around a piece of gas pipe, with the spring inserted ; this causes the spring to be uniformly heated. Being heated to a cherry red, the spring must be plunged into clear water slightly heated, and held there till quite cold.

If it is then found black and if not evenly mottled with white spots, it would indicate an insufficient hardness arising from the quality of the steel or insufficient heating ; steel, when of good quality, is sufficiently heated when it just forms a scale on coming from the fire.

If the hardening process is found difficult, the water should be salted till it becomes a strong brine, and the hardening repeated till the steel appears white when taken out of the water, as it will if well hardened ; the whiteness of the surface being a better test than the file would be, because steel of a straw color will not file, and any degree of hardness between straw color and white cannot be distinguished by this test.

The temper of a spring lowered from a white hardness to a blue, is not the same as that lowered from a black or even a mottled hardness to a blue; and hence, for the sake of evenness in the temper, all those of a dark or mottled appearance should be reheated.

The most reliable method of tempering an ordinary spring, is to "blaze it off;" *i. e.*, boil it off in the oil, heating and reheating the oil to a blaze, and dipping and redipping it in two or three times ; after the boiling and the blazing takes

place freely all over the spring, and has, on the last removal from the tank, burned out at any one point, it should be placed in warm water and left to cool.

The thicker the spring, the longer it should be subjected to this process of blazing and dipping, so that every part of the spring shall be equally heated inside and out. It is well that the spring should be reversed and revolved in the oil, in order that heat may not accumulate at any one point, and thus make an uneven temper. A good oil composition for hardening consists of:

Spermaceti oil	48	parts.
Neats'-foot oil	47	"
Rendered beef suet	4	"
Resin	1	"

The tank in which it is placed should have a close-fitting cover, which will put out the blaze when the tempering is finished.

The colors adopted are not invariable for even the same purposes; different makers temper their tools somewhat differently. Watchmakers' tools are heated in the flame of a blow-pipe or of a lamp, and are hardened either in the air, or by plunging their points into wax or tallow. Saws and springs are often hardened in mixtures of wax and oil, tallow or suet; the tempering is done by "blazing off" the grease. Car-springs and carriage springs are heated to a low red heat, cooled in hot or in warm oil, and left without further tempering. Large pieces must be "drawn" more in tempering than small ones. The peculiar steels mentioned previously require a very different treatment from the carbon steels.

Chrome steel may be forged like any other, but all tools drawn from a large body to an edge should be allowed to cool off after forging, and should be reheated for tempering, as the interior of the mass retains the heat at which it was forged long after the external surface has cooled. It is still too hot for tempering, and is liable to crack on cooling.

The following table shows more generally the proper treat-

ment of tool-steels in tempering for various purposes, water being used in cooling:

SCALE FOR TEMPERING TOOLS OF CARBON STEEL.

MATERIAL CUT.	TOOLS URGED BY—									NOMENCLATURE.
	PRESSURE.				IMPACT.					
	A	B	C	D	E	F	G	H	K	
Unannealed Steel.	0	1	2	2	3	4	2	2	7	0. To remain as dipped.
Annealed Steel.	1	2	2	3	3	5	3			1. Light straw color. 2. Dark straw color.
Chilled Cast iron.	0	0								3. Orange color. 4. Reddish purple color.
Hard Cast iron.	0	2	3	3	4	2				5. Purple color. 6. Bluish purple color.
Soft Cast iron.	1	3	3	3	5	3				7. Dark blue color. 8. Light blue color.
Gun Metal (Bronze).	1	2	3	3	6	6				9. Bluish gray color. 10. Soft.
Yellow Brass.	2	3	3	3	6	6				A. Turning or planing tools.
Soft composition.	3	4	3	3	7	7				B. Drills, bitts. C. Taps, dies.
Wrought Iron.	3	6	3	3	7	7	4			D. Rimmers. E. Cold chisels.
Copper.	4	6	3	3	7	7	4			F. Flogging chisels. G. Caulking tools.
Wood.	6	6								H. Hammers. K. Springs.

Chrome steels, and also the wolfram steels, should be hardened at the lowest heat possible—a dark cherry red, seen only in the shade—and they will then be found to have maxi-

mum strength and hardness. The temper is not "drawn" for ordinary tools. Pieces of small size, or having thin edges, are slightly drawn in temper at the edge or point. Too great heat causes the grain to become coarse and granular, and the article must then be reheated and slowly cooled to restore the fine grain required in good tools. When annealing it this steel should be slowly and uniformly heated to a barely visible red-heat, and laid aside to cool under lime, ashes, or sand. With careful handling it can be made to weld perfectly.

The Changes due to Hardening and Tempering are not fully understood. The temperature at which the change occurs with common tool-steel seems to be about that at which the metal begins to exhibit color—a low, barely visible red-heat, as seen in the dark. Any treatment which, quickly reducing the temperature, causes the passing of this line on the scale of temperature, hardens steel. It would seem, therefore, that at a low heat but slight cooling is necessary to harden steel. Even metals in fusion, when their melting points are below this critical temperature, may be used in tempering, and will produce this effect to an extent which is determined by the difference of the temperatures of the metals at the moment, and by their relative conductivities and capacities for heat.

Water is the most efficient of all fluids if properly used, as it has a high specific heat and great capacity for taking up heat while changing in temperature or while vaporizing. It acts most efficiently when thrown upon the steel in fine spray from under great pressure, and a stream of flowing water is better than still water where great hardness is desired, as a vaporous cushion protects the surface of the metal in quiet water, and checks the absorption of heat; a stream of boiling water often hardens more than does still, but cold, water. The highest efficiency is attained when the amount of water used is just sufficient to evaporate completely.

The change which occurs in hardening steel is, then, a physical alteration of structure which occurs at some point between 800° and 1,000° Fahr. (427° to 538° Cent.), and it is

the more complete as the reduction of temperature of the metal is the more rapid. Jarolineck places the critical temperature at 932° Fahr. (500° Cent.), as determined by him experimentally. The change would seem to be a kind of crystallization which is removed by slow cooling, the crystallizing force yielding to that of cohesion as the metal gradually cools, but retaining the power and preserving the molecular arrangement which it exhibits at high temperatures if the cooling takes place too suddenly to permit rearrangement of particles while cooling. Boiling water has been used by W. Matthieu Williams to *anneal* steel of even a considerable degree of hardness.

Compression of Steel while Cooling has been practiced* by Clémendot. Thus, metals, if compressed by a sufficiently high pressure to somewhat increase their density, and held thus compressed while cooling from a full "cherry-red" heat, are permanently strengthened. The effect upon steel is precisely that obtained by tempering. This process is therefore called by him "*tempering by compression.*"

Hammering produces this effect, but hydraulic pressure is better.

The advantages claimed for the Clémendot method are: (1.) It may be graduated and adapted to any special case. (2.) The operation may be specified in advance by prescribing the intensity of pressure to be applied. (3.) It is a more exact, manageable, and certain process than the usual methods of hardening and tempering.

The effect of this compression has been found by M. Lan† to be an alteration in the proportion of combined carbon, as in the tempering by the ordinary method, thus:

Carbon total.	A.	B.	C.	D.	Mean.	Free C.
Uncompressed steel..0.70	0.49	0.50	0.47	0.50	0.490	0.210
Compressed steel....0.70	0.60	0.59	0.55	0.60	0.585	0.115

Corrosion of Iron and Steel, and the chemical changes which produce or accompany that method of dete-

* *Jour. Frank. Inst.*, Sept., 1882 (Vol. cxiv., No. 681), p. 238.

† *Comptes Rendus*, Vol. xciv., 1882, p. 952.

rioration, cannot go on in the air except when both moisture and carbonic acid are present, or unless the temperature is considerably higher than that of the atmosphere. When exposed to the action of free oxygen, however, under either of these conditions, the metal is corroded—rusts—rapidly or slowly, according to its purity. Wrought iron rusts quickly in damp situations, and especially when near decaying wood or other source of carbonic acid; while steels are corroded with less rapidity, and cast iron is comparatively little acted upon. The presence of acids in the atmosphere accelerates corrosion, and the smoke of sulphur-charged coal, or smoke charged with pyroligneous acid, frequently causes the oxidation of out-of-door iron structures.

The composition of the rust forming upon surfaces of iron is determined by the method of oxidation, but is principally peroxide of iron. Calvert gives the following:

	Rust from Conway Bridge.	Llangollen.
Fe_2O_3	93.094	92.900
FeO	5.810	6.177
Carbonate of iron	0.900	0.617
Silica	0.196	0.121
Ammonia	traces	traces
Carbonate of lime	.....	0.295

A series of experiments made to determine the effect of different oxidizing media, after four months' exposure of clean iron and steel blades, gave the following result:*

Dry oxygen—no oxidation.

Damp oxygen—in three experiments one blade only was slightly oxidized.

Dry carbonic acid—no oxidation.

Damp carbonic acid—slight appearance of a white precipitate upon the iron (found to be carbonate of iron).

Dry carbonic acid and oxygen—no oxidation.

Damp carbonic acid and oxygen—oxidation very rapid.

Dry and damp oxygen and ammonia—no oxidation.

Indicating that oxidation is principally due to the presence of carbonic acid with oxygen.

* *Chemical News*, 1870–1871.

When distilled water was deprived of its gases by boiling, and a bright blade introduced, it became in the course of a few days here and there covered with rust. The spots where the oxidation had taken place were found to mark impurities in the iron, which had induced a galvanic action, precisely as a mere trace of zinc placed on one end of the blade would establish a voltaic current.

Kent has shown * that the rusting of iron railroad bridges is sometimes greatly accelerated by the action of the sulphurous gases and the acids contained in the smoke issuing from the locomotive, and that sulphurous acid rapidly changes to sulphuric acid in the presence of iron and moisture, thus greatly accelerating corrosion. Iron and steel absorb acids, both gaseous and liquid, and are therefore probably permanently injured whenever exposed to them.

Calvert experimented upon iron immersed in water containing carbonic acid, in sea water, and in very dilute solutions of hydrochloric, sulphuric, and acetic acids. A piece of cast iron placed in a dilute acetic acid solution for two years, was reduced in weight from 15.324 grammes to 3½ grammes, and in specific gravity from 7.858 to 2.631, while the bulk and outward shape remained the same. The iron had gradually been dissolved or extracted from the mass, and in its place remained a carbon compound of less specific weight, and small cohesive force. The original cast iron contained 95 per cent. of iron and 3 per cent. of carbon, the new compound only 80 per cent. of iron and 11 per cent. of carbon. Iron immersed in water containing carbonic acid was also found to oxidize rapidly. Iron exposed to the wash of the warm aerated water of the jet condensers of steam engines is often very rapidly oxidized, and the mass remaining after a few years often has the appearance, texture, and softness of plumbago, so completely is the iron removed and the carbon isolated.

Mallett, experimenting for the British Association,† found the rate of corrosion of cast iron greatly accelerated by

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* *Iron Age*, 1875.

† Proc. Inst. C. E., 1843.

irregular and rapid cooling, and retarded by a slow and uniform reduction of temperature while in the mould.

The rate of corrosion is usually nearly constant for long periods of time, but it is retarded by removal of the coating formed by the rust, as, if left, it creates a voltaic couple, which accelerates corrosion.

Hard iron, free from graphite, but rich in combined carbon, rusts with least rapidity, and with about equal rapidity in the sea as in the air, in an insular climate. Two metals of different character as to composition or texture being in contact, the one is protected at the expense of the other. Foul sea-water, as "bilge-water," corrodes iron very rapidly.

The rate of corrosion of iron is too variable to permit any statement of general application. In several cases the plates of iron ships have been found to be reduced in thickness in the bilges and along the keel strake, at the rate of 0.0025 inch (0.06 millimetres) per year, as ordinarily protected by paint, while it is stated that iron roofs, exposed to the smoke of locomotives, have sometimes lasted but four years.

The iron hulls of heavy iron-clads have sometimes been localiy corroded through in a single cruise, where peculiarities of composition or of structure, or the proximity of copper or of masses of iron of different grade or quality had caused local action.

Durability of Iron and Steel.—Twaite* gives the following as the measure of the probable years' life of iron and steel undergoing corrosion, assuming the metal to be uniform in thickness. Thin parts corrode most rapidly.

$$T = \frac{W}{CL},$$

in which W is the weight of the metal in pounds, of one foot in length of the surface exposed; L is the length in feet, of its perimeter, and C a constant, of which the following are values:

* Molesworth, p. 32, 21st ed., 1882.

VALUES OF *C*.

MATERIAL IN	SEA WATER.		RIVER WATER.		IMPURE AIR.	AVERAGE SEA WATER.
	Foul.	Clear.	Foul.	Clear, or in air.		
Cast iron	.0656	.0635	.0381	.0113	0476	.....
Wrought iron	.1956	.1255	.1440	.0123	.1254	.....
Steel	.1944	.0970	.1133	.0125	.1252	.....
Cast iron, skin removed	.2301	.0880	.0728	.0109	.0854	.....
" galvanized	.0895	.0359	.0371	.0048	.0199	.....
" in contact with brass, copper, or gun bronze						0.19 to 0.35
Wrought iron in contact with brass, copper, or gun bronze						0.30 to 0.45

When wear is added to the effect of oxidation, the "life" of a piece of iron or steel may be greatly shortened. If kept well painted, multiply the result by two.

The mean duration of rails of Bessemer steel is, according to experiments in Germany, about sixteen years. Ten years of trial at Oberhausen, on an experimental section of the line between Cologne and Minden, has shown that the renewals during the period of trial were 76.7 per cent. of the rails of iron of fine grain, 63.3 of those of cementation steel, 33.3 per cent. of those of puddled steel, and 3.4 per cent. Bessemer steel.

The Preservation of Iron and Steel is accomplished usually by painting, sometimes by plating it.

As the more porous varieties will absorb gases freely and some liquids to a moderate extent, Sterling has proposed to saturate the metal with mineral oil; heating the iron and forcing the liquid into the pores by external fluid pressure, after first freeing the pores from air by an air-pump, or other convenient means of securing a vacuum in the inclosing chamber.

Temperatures of 300° to 350° Fahr. (150° to 177° Cent.), and pressures of 10 to 20 atmospheres are said to be sufficient for all purposes.

Voltaic action may be relied upon to protect iron against corrosion in some situations. Zinc is introduced into steam boilers for this purpose.

CHAPTER VII.

COPPER, TIN, ZINC, LEAD, ANTIMONY, BISMUTH, NICKEL, ALUMINIUM, ETC.

Copper (Latin *Cuprum*, Cu.) has been known to mankind from some very early, and even prehistoric, period, and was applied in the manufacture of tools and useful implements, probably long before iron was used, or even known. It exists native and is comparatively easily reduced from its ores and worked, and hence could be obtained and worked at a time when the art of reducing the comparatively refractory ores of iron had not been acquired.

Qualities.—The metal has a deep red color, the only metal except titanium having that color, is heavy (S. G. 8.8 to 8.93) very malleable and ductile and has considerable tenacity. Its hardness is usually rated at 2.5 or 3. When warm, and when rubbed with the hand, it gives out a strong odor of a peculiar and somewhat disagreeable character. Commercial copper is contaminated with silver, lead, antimony and iron; although the native copper, as much of that obtained from Lake Superior, is sometimes almost chemically pure.

The melting point of copper is given by Pouillet as 2050° Fahr. (1121° C.) and vaporization occurs at the white heat, the vapors burning with the green flame which gives the characteristic lines of this metal in the spectroscope. It is a remarkably good conductor both of heat and electricity. Copper does not oxidize in dry air at ordinary temperatures, but does so rapidly in a moist or acid atmosphere, and at temperatures approaching the red heat.

Of this metal from 175,000 to 180,000 tons are annually

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* "Prehistoric Times." † Vol. i. p. 12 (Ed. 1856.)

consumed, principally from the United States, Cornwall, Chili and Bolivia. It is supplied in the form of bars, wire, sheet and ingots, which latter are re-melted to obtain copper and alloys in castings. It is, next to iron, the most important and useful of the metals. Its valuable properties will be described at greater length, presently.

Copper Ores are distributed very widely over the earth's surface and are found in every large political division of the world. It exists in a great variety of forms, usually as sulphide or oxide; but in some cases, as in the United States, on the south shore of Lake Superior, is found in the form of native copper and in enormous quantities, and almost equally enormous quantities are now mined in Montana, Arizona and other western localities.

Metallic copper occurs in masses, in flakes and sheets, in threads, and in spongy masses dissemimated through rock crevices, earthy gangue or even solid rock masses. Enormous blocks and extensive masses are found and worked in several of the mines of Lake Superior. These great blocks sometimes weigh several hundred tons. In this condition it is one of the most expensive ores of copper; for the metal is excessively tough, and cannot be blasted, but must be prepared for the market by being cut up with tools; and the presence of siliceous gangue in the mass renders this operation very difficult. In the deposits worked in and near the Calumet and Hecla mine of that district, it exists in the red conglomerate in a peculiar form, permeating the rock very uniformly in just such a proportion as gives maximum ease and cheapness of mining and preparation.

The metallurgists find that comparatively few of the copper minerals are of much importance, by far the largest proportion of this metal annually produced by the mines of the world being obtained from copper pyrites.

Phillips gives the following list of the commercial ores of copper.*

Native Copper is cubical, occurs crystallized in octahedrons, sometimes modified, lamellar, filiform, or arborescent, and has a specific gravity = 8.83. No known locality produces such

* *Vide* "Elements of Metallurgy;" J. A. Phillips. Lond., 1874.

large quantities as the region of Lake Superior, where it occurs in veins intersecting trap rocks, frequently associated with metallic silver. In small quantities, native copper is of frequent occurrence, but except in the region above mentioned, it is not of much importance as an ore. It is generally remarkable for great toughness.

Cuprite (red oxide of copper)—composition, Cu_2O—is cubical, generally in cubes and octahedrons, of a ruby-red color, with a specific gravity = 6, and contains, when pure, 88.80 per cent. of copper.

Melaconite (black oxide of copper)—composition, CuO—is cubical; rarely found crystallized, but more commonly earthy; is massive, or pulverulent, affording, when pure, 79.82 per cent. of copper.

Malachite (green carbonate of copper) crystallizes in the oblique system, the crystals being often very complicated; occurs more frequently massive or incrusting the surface, being botryoidal or stalactitic. The specific gravity = 3.7 to 4.1. Its composition is $CuCO_3$, CuH_2O_2, yielding, when pure, 57.33 per cent. of copper. This mineral frequently occurs near the surface, in veins producing sulphides and other ores of copper, and has probably been derived therefrom by atmospheric agencies.

Azurite (blue carbonate of copper)—composition, $2CuCO_3$, CuH_2O_2—crystallizes according to the oblique system, and also occurs massive. Its specific gravity is 3.5 to 8.81; containing, when pure, 55.16 per cent. of metallic copper. It occurs largely in South Australia, and formerly at Chessy, near Lyons; and is hence sometimes called Chessylite.

Chalcopyrite (copper pyrites)—composition, Cu_2S, Fe_2S_3—is prismatic, often in hemihedral forms, though more commonly massive, with specific gravity = 4.2; containing, when pure, 34.81 per cent. of copper. This, which is the most important ore, rarely contains, as sent to market, more than 12 per cent. of that metal, and frequently less.

Bornite (purple copper ore) crystallizes in the cubical system, and has a specific gravity 4.4 to 5.5. Its composition varies, sometimes $3Cu_2S$, Fe_2S_3; copper from 50 to 70 per cent.

The United States supplies copper to the world. Of the nearly 70,000 tons produced per annum, the Lake Superior mines yield about one-half, western mines nearly one-half.

The copper sent into the market from the Lake Superior district is principally derived from crushed low-grade rock, containing native copper; that coming from the southern Rocky Mountains is derived from oxides, and that from the Butte district of Montana and from Utah is obtained from argentiferous ores. The copper smelted in the Appalachian sections is from pyritous ores. Altogether they yield between 60,000 and 70,000 tons annually. The output in 1845 was but 100 tons,* that in 1884 was about 125 millions of pounds (nearly 55,000,000 kilogs), valued at 12½ cents per pound, or over $15,000,000, and was increasing at the rate of 20 to 25 per cent. annually. Much of this product is exported. The refining is done in works situated at Baltimore, Md., Oxford, N. Y., Elizabeth, N. J., Ansonia, Conn., Phœnixville, Pa., Chicago, Ill., and farther west.

The production of Great Britain (Cornwall) nearly equals that of the United States, while that of Chili is large.

Copper smelting in the United States is conducted, by three principal methods, according to the character of the ores. These are: †

Fusion of native copper and refining;

Fusion of carbonates and refining;

Reduction of sulphuretted ores and refining.

Lake Superior copper is of the first class. It is melted down as received with its gangue and with 6 or 8 per cent. limestone and 10 per cent. refinery slags. The charges are about 12 tons each, which are worked in a large reverberatory furnace about 12 hours. The slags are skimmed and the richer grades are refined, while the remainder form a part of the next charge. The refining and ladling take 5 hours.

Cupola furnaces are sometimes used, which take 20 tons at a run, of which 40 or 45 per cent. is limestone, 30 to 35 per

* "Metallic Wealth of the U. S.": Whitney.

† J. Douglas, Jr., in "Mineral Resources of the U. S." Gov't Print. (Geol. Survey; Interior Dept.), Washington, D.C., 1883.

cent. anthracite coal and 4 per cent. copper. The lining furnishes a considerable amount of silica and is rapidly cut out and often lasts but for a single operation.

The Processes of Reduction of copper ores differ with their composition. The oxides and carbonates are easily reduced, by fusion, in presence of carbon, with a siliceous flux. The copper is promptly reduced to the metallic state. Some loss is usually met with in consequence of the tendency of the oxide to form a silicate, and this is checked by supplying either an alkaline base, usually lime, or by mixing with sulphuretted ores, of which the sulphur unites with the oxygen present and thus permits complete reduction.

The sulphides are usually first roasted and thus converted to a considerable extent into oxide. This roasted ore is then smelted, sometimes in reverberatory and sometimes in blast furnaces, and this roasting and smelting is repeated until a "regulus" is obtained consisting of a nearly pure sulphide. This product is finally roasted with free access of air until, having been brought to a certain state, in which sulphide and oxide exist in the right proportion, a double decomposition occurs, yielding sulphurous acid and metallic copper ($2CuS + Cu_2O = SO_2 + Cu_6$) which latter is of fair degree of purity, and is known either as "coarse copper," or "blister copper," etc., etc. This is finally purified before it is sent into the market as ingot copper. The final process consists in melting down in the presence of an oxidizing flame and with fluxes, and, after removal of slag, "poling" or stirring with green birch rods or poles to produce thorough mixture and to decompose all oxide. Care and skill are required to prevent either "underpoling," which would leave oxide in the metal, or "overpoling," which reduces other metals and makes an alloy of reduced value.

This last process of refining is the only one necessary in the treatment of the native copper of Lake Superior.

Details of Reduction of Copper Ores.—In detail, these processes are very complex, although sufficiently simple in their theory. The process of reduction usually practised consists of roasting to expel sulphur and arsenic, melting to

flux out iron oxide by siliceous fluxes, and roasting and smelting in one operation to obtain the commercial metal.

The first operation is that of breaking up the ore into small and, as nearly as may be, uniform pieces, removing useless gangue and assorting the ore in such a manner as to facilitate the processes of reduction. The next process is that of calcining, roasting, about three tons at a time, in a reverberatory furnace on a long and wide level hearth—often 15 or 16 feet by 12 or 14 (4.6 or 4.9 metres by 3.7 or 4.3)—where it is spread in a thin layer and exposed to the action of the flame. The hearth is bricked over and cemented with fire-clay and the roof is a low arch. Openings from the fire-place admit the heating gases; others from the atmosphere provide for oxidation by the admission of air; and others at each side are arranged for the discharge of the roasted ore into a low arched space, or chamber, under the furnace. The ore is admitted through openings in the top surmounted by hoppers, into which it is filled and left to heat gradually until dropped into the furnace.

The fuel, a soft coal or a mixture of bituminous and semi-bituminous coal, is burned with restricted air-supply, and the resulting carbonic oxide passes into the furnace, where, meeting the required air, it burns to carbon dioxide, and the long flame sweeping over the hearth, heats the ore to the temperature needed to roast it. While thus exposed to the heat of the burning gas, the ore is continually stirred and raked over to bring all parts of the charge into contact with the flame.

During this process, any sulphur present is exposed to oxygen at high temperature, and a part, but never all, is oxidized, passing off as sulphurous acid; or oxidizing in small amount still further, it unites with the copper to form a sulphate. The arsenic passes off as white arsenic, arsenious acid, in the form of vapor. The copper also combines, to a slight extent, with oxygen, to form the suboxide of copper, and any salt of iron present in sulphides becomes changed to oxide.

In some cases, the roasting is accomplished by indirect heating and out of contact with the flame from the grate,

and the vapors thus isolated are diverted for the purpose of converting the sulphurous acid into sulphuric acid, which latter is collected in the usual way in leaden chambers. Where the gases from the fuel mingle with the vapors of sulphur, and other products of roasting, they are often all carried into a "condenser," in which a spray of water is introduced to wash the air clean before discharging it into the atmosphere.

The ore is now ready to be smelted. If any ores are to be treated which are free from arsenic and sulphur, they are not roasted, but are mixed with the other ores after the latter are calcined, and the mixture is then smelted.

The smelting furnace, called often the "ore furnace," is a small reverberatory furnace, fitted with a comparatively large grate, and having a hearth so formed that the molten ore may lie on it in a shallow pool, deepest near the middle of one side of the furnace. The charge is about one and a half tons of ore, flux and slag derived from a later operation, of which the ore amounts to about two-thirds, while the flux and slags make up the other third. This being charged upon the bed of the furnace, the slag soon melts, and the whole charge later becomes molten and "boils" rapidly with disengagement of sulphurous acid. In the course of four hours, or less, the attendant uses his rubble, stirring the charge thoroughly, and at the same time raising the heat of the furnace until the coarse metal and slag separate. When this is done, the "matt" or "regulus" of partly refined or "coarse metal" is tapped off into a cast-iron box having a perforated bottom, through which it runs into a tank containing water, and thus becomes granulated. The slag is run into moulds, and the blocks so formed—of silicate of iron, principally—are useful in building.

The regulus is only one-third copper, the rest being sulphur and iron, and the whole being a sulphide of copper and iron. It is charged again into the roasting furnace, and calcined for twenty-four hours, the workmen raking it over ten or twelve times in the interval, as the sulphur burns out of the more exposed portions. The loss of about one-half the

sulphur reduces the charge to a mixture of iron oxide, copper sulphide, and some iron sulphide.

This calcined regulus is then charged with slags from later processes in equal or greater quantity, and with any pure oxides or carbonates at hand, into a melting furnace, and there held in fusion about six hours, when the resulting regulus and slag are tapped off. The former may be run into water as before, and thus made "fine metal," or cast in pigs as "blue metal," containing about seventy-five per cent. of copper. The best copper is found in the pigs last cast, the first producing a less pure metal called, later, "bottoms," or "tile copper." When less rich in copper, it is again calcined and melted to obtain block or coarse copper, containing more metal. The slag, or "metal slag," as it is called, contains, usually, enough of copper to make it advisable to re-work it with the ores, as already described, or separately.

Still another repetition of the calcining and melting processes removes a part of the remaining sulphur, and yields what is called "blistered copper;" the "blisters" on the surface of the ingots giving evidence of the escape of sulphurous acid while solidifying.

Finally, this blistered copper is re-heated in charges of six or eight tons weight, with free access of air, and the arsenic and sulphur remaining are converted into arsenious and sulphurous acid, and the iron, lead, tin, and other oxidizable impurities are converted into oxides before the charge is allowed to melt, this preliminary operation occupying about six hours. The metal is then melted down and sampled to determine how the process of "toughening" shall be conducted. This consists in "poling," or stirring the molten charge with poles, from young saplings of birch, usually, until sample ingots exhibit the density, toughness, fineness of grain, and pure copper color which indicate the desired quality. When right, or at "tough-pitch," it is run into ingot moulds and becomes "tough-cake." The process of poling results in the removal of the oxygen taken up by the copper in the earlier processes by contact with the hydro-

carbons and the pure carbon of the wood. Overpoling causes the absorption of carbon, and gives the same brittleness which had been caused by oxygen; and the avidity with which copper takes up both these elements makes this operation one demanding great care and skill.

Where sheet copper is to be made, lead is often added before casting, to give greater malleability, by fluxing out the tin and other alloy; this lead is oxidized, and is all removed again with other oxides in the slag.

Modifications of this process are adopted with leaner ores; and the melting and poling only is necessary with pure native copper, such as is mined in the Lake Superior region in the United States.

Copper is reduced at Ore Knob, N. C., from very pure but lean ores, containing from two to five per cent. copper. These ores are picked over carefully, and sent to the calcining ground, where they are roasted in heaps, under sheds 240 to 300 feet long and 34 feet wide, the piles measuring 100 tons of fresh, or 50 tons of roasted ore. The roasted ore contains four to five per cent. copper.

Fusion of the ores takes place in furnaces resembling cupolas, and the mattes are smelted in the same kind of furnace. The latter contain twenty or twenty-five per cent. copper. These "single mattes" are roasted in heaps, and fused in shaft-furnaces for black, or pig copper, and "double," or concentrated mattes. This black copper contains ninety to ninety-five per cent. metallic copper, some iron, and other elements.

The mattes are re-worked, and the crude copper is refined in reverberatory furnaces, taking five tons at a charge; the product consists of 99.8 per cent. metallic copper.

The wet processes of copper extraction are divided by Hunt * into three classes:

I. Those in which the copper in sulphuretted ores is rendered soluble in water, after roasting them, converting them into chlorides or sulphates.

II. Those in which free hydrochloric or sulphuric acid is

* Trans. Am. Inst. Min. Engineers, vol. x., p. 11.

used to dissolve the metal from oxides or roasted ores. These are usually costly processes, and are seldom practised.

III. A method by which a hot solution of ferrous chloride with common salt is used to convert copper oxides into chlorides. This is the Hunt and Douglas method.

The Hunt and Douglas process of extracting copper from its ores consists, as practised in North Carolina and in Chili, in the dissolving of the oxides in a hot solution of protochloride of iron and common salt, thus converting the protochloride into peroxide of iron, and the oxide of copper into protochloride and dichloride, the latter of which is soluble in strong brine. From this solution the copper is precipitated by the introduction of scrap iron. This method involves almost no consumption of chemicals other than common salt, which is added to supply unavoidable losses. The sulphurous ores are converted into oxides by crushing, grinding, and calcination in three-hearthed reverberatory furnaces. The iron consumed amounts to seventy per cent. of the copper reduced as cement copper. One furnace roasts two and a half to three tons of ore per day, using one-third cord of wood.

Special cases.—Carbonate ores sometimes supply excellent copper, although rarely, if ever, equal to that found native. They are now smelted in cupola furnaces, in which the parts exposed to highest temperature are lined with copper cooled by water-jackets. These furnaces are capable of smelting 50 tons per day. Oxides are similarly smelted, using about 1 ton of fuel (coke) for 6 or 7 tons of ore. The reduced copper is run into pigs or ingots of 250 to 300 pounds (115 to 160 kilogs., nearly) weight, and containing 2 or 2.5 per cent. slag.

Sulphuretted ores are smelted both in reverberatory furnaces and in cupolas. By the first method, the ores and slags, containing a mean of about 33 per cent. copper, are treated in charges of 4 tons each, and about four charges are worked in 24 hours. The matte is roasted and fused until a regulus is obtained containing 70 per cent. copper. This is slowly melted, the sulphur oxidized out of it, the slag skimmed and the charge oxidized sufficiently by the air-

blast to form oxide of copper and sulphurous acid and to produce the reactions,

$$2\,CuO + CuS = 3Cu + SO_2$$
$$CuO + SO_2 = Cu + SO_3.$$

The gases thus carry some sulphuric acid. The metal should finally contain over 95, and even 98, per cent. copper. With labor at $2.25 and $1.50 per day and coal at $4.00 per ton, the cost of reduction is about $35 per ton of copper produced.

Cupolas and modifications of the broad-mouthed furnace of Rachette are also used for smelting the sulphuretted ores, and the cost is thus often reduced some 30 per cent. These furnaces are not as well adapted to treating a wide variety of ore as the reverberatory.* The latter is much better fitted than the former for smelting arsenical ores, and for use where wood is cheap, and charcoal, coal or coke expensive. The slag from the cupola is cleaner, the cost of repair may be made less, and no temporary loss of copper occurs as by its permeation of the bed of the reverberatory.

When the ore is very lean, or contains elements difficult of removal by smelting, or when the separation of silver or other valuable metals alloying with copper is necessary, wet methods of reduction are practised. The copper is either separated by solution or by separate precipitation. Such processes are adopted to save the metal otherwise lost in mine waters either below ground or flowing from ore-heaps.

Copper reduced by the dry method is liable to considerable injury by absorption of oxygen while in fusion. The extent of this injury is well shown by the behavior of bars made for test by the author† in the course of investigations of the properties of bronze alloys.

An analysis was made of the turnings of these bars for the purpose of learning whether the chemical composition would account for the presence of blow-holes and the lack of ductility.

* "Mineral Resources of the United States." J. Douglas, Jr., p. 270.

† Report of U. S. Board, vol. i.; 1878.

The result was the discovery of an extraordinary amount of suboxide of copper in bar No. 1. This was no doubt caused by repeated meltings.

The following are the analyses:

	NO. 1. Per cent.	NO. 30. Per cent.
Metallic iron	0.020	0.014
Metallic zinc	0.014	0.057
Metallic silver	0.035	0.014
Metallic arsenic	none	none
Metallic antimony	none	none
Metallic tin	none	....
Metallic bismuth	none	none
Metallic lead	trace	trace
Metallic copper	87.900	96.330
Suboxide of copper	12.086	3.580
Carbon	none	....
	100.055	99.995

No. 30 had been less exposed to the air than No. 1 and less frequently remelted.

Metallic Copper, although both malleable and ductile, excels in the first quality and finds more frequent employment in the form of sheet metal than in that of wire. These qualities are possessed in the highest degree by the pure metal and are greatly impaired by very slight admixture of foreign elements of metallic alloy. Its tenacity and hardness, although less than that of iron or steel, is greater than that of any other non-ferrous material; and its power of resisting oxidation, of taking a fine polish and of easy working, make it an extremely valuable material to the engineer.

Good copper should have a strength of at least 30,000 pounds per square inch (2,109 kg. per sq. cm.); and cold-working, by wire-drawing, for example, raises its tenacity sometimes to double that amount. If worked hot in the presence of oxygen, it is liable to serious injury by internal oxidation, and, in presence of carbon, by the formation of the carbide. It becomes hard and brittle when hammered or wire-drawn,

and its ductility is restored by annealing, by *sudden* cooling—the opposite of the treatment required in annealing steel.

It can be forged, when pure, either hot or cold, more easily than iron. It loses strength with increasing temperature. Its oxide and carbonate are poisonous, and its surface is therefore tinned when it is used for culinary purposes or where liable to serious injury by corrosion.

Copper is very seldom cast, unalloyed, in consequence of the difficulty of obtaining sound, strong castings. When fluxed with phosphorus, it is, however, possible to make castings of good quality; and that metalloid is one of the best known fluxes for all its alloys. "Phosphorus-copper" has a strength, according to Abel, of from 30,000 to 50,000 pounds per square inch (2,103 to 3,515 kgs. per sq. cm.), as the percentage of phosphorus added rises from one to three or four per cent.

Riche* found that the density of copper, subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the re-heating; while in the first case the mechanical action increases the density, in the second, mechanical action diminishes it.

Professor Farmer has informed the author that he has succeeded in depositing copper, from cyanide solutions by electrolytic processes, harder than untempered steel.

Copper of Commerce.—The copper found in the market is of several kinds, each known commercially by a different name.

"Lake Copper" is that obtained in the neighborhood of Lake Superior, and is principally native copper. It is remarkably pure, and when well handled in melting and poling, it is considered unexcelled for purposes as, for example, conductors of electricity, in which every trace of foreign matter reduces appreciably, and often seriously, the value of the copper. The best Lake copper has ninety-three per cent. of the conductivity of chemically pure copper.

Western, South American, and European coppers are

* *Comptes Rendus*, vol. 55, 1862; pp. 143–7.

usually not native coppers, nor are the coppers obtained from nearly every other part of the world. Japanese copper is a richly colored metal, which comes into the market in small ingots. All commercial coppers obtained from other than deposits of native copper are likely to be contaminated by the presence of arsenic, sulphur, oxygen, and alloyed with lead, tin, iron, nickel, bismuth, silver, and antimony, of which sulphur, oxygen, and antimony are most troublesome.

Copper, as sold in the market, contains from one-tenth to one per cent. of foreign matter; an excellent sample contained 99.9 per cent. copper. One-tenth of one per cent. of impurity, according to Egleston,* may reduce the conductivity of the metal ten per cent. The presence of one-half per cent. may make the metal worthless for many purposes. The following are analyses of three samples:†

AMERICAN COPPER.—EGLESTON.

	ORE KNOB.	L. SUPERIOR.	BALTIMORE.
Metallic copper	99.80	99.83	99.65
Oxygen	0.39	0.15	0.00
Sulphur	0.00	0.00	0.00
Silver	0.05	0.026	0.066
Lead	0.01	0.016	0.044
Arsenic	0.00	0.00	0.088
Antimony	0.00	0.00	0.035
	100.25	100.02	99.893
Silver in 2,000 pounds	14.6	7.03	19.75

A sample of Swiss copper, found by Berthier ‡ to possess extraordinary softness, ductility, and malleability, was composed of

Copper	99.12	Calcium	0.33
Potassium	0.38	Iron	0.17

and that author concludes that its valuable properties are

* Trans. Inst. Min. Engineers, vol. x., p. 63.

† Ibid., p. 54.

‡ "Essais par la Voie Sèche."

due to the presence of the alkaline metals. Mallet proposes* to introduce an alloy of sodium and tin in the manufacture of gun-bronze to secure freedom from oxide, using 0.05 per cent. sodium, or less.

Copper is too soft, and usually too weak, to be of as great value in the arts as iron, even were its price to admit of such use. It is principally employed in the form of sheets and wire. Copper in heavy sheets is sometimes used for the "fire-boxes" of locomotives, where iron would be rapidly corroded; it is extensively used in making large vessels for manufacturers of chemicals and pipes. Copper pipes of large size, such as are used on marine engines for steam and feed pipes, are made by rolling up sheet copper and brazing the edges together. Small pipe is sometimes drawn to size in dies; feed and "blow-off" pipes are usually thus made; this "solid-drawn" pipe is more costly, but much better, than brazed pipe."

The ductility, malleability, and the considerable strength of copper, permitting its being worked into rods, bars, wire, or sheets with equal facility, make it, next to iron, the most useful of the metals. Its quality is so greatly dependent upon its purity and freedom from oxidation or admixture with other metals, that it is very important to the engineer to see proper precaution observed in obtaining it for structural purposes.

Working by the hammer, in the rolls, or in the wire-mill, causes great increase in tenacity, while carelessness in melting and casting it may render it worthless for the purposes of the engineer, and even the strengthening processes cannot be carried far except with occasional annealing. It may be worked either cold or hot, and forged like iron, if not so highly or so long heated as to cause serious oxidation. It oxidizes quickly at high temperatures, and also when exposed to a damp atmosphere. Fusing it under a layer of salt, it is less liable to injury in the foundry.

Thin sheet copper is subject to a peculiar deterioration of strength, with time, which has been studied but little, and

* "Construction of Artillery," p. 97.

the cause of which is not fully ascertained. This degradation of quality is singularly irregular and erratic, and affects the product of the best mills, as well as low grade copper. It has been noticed particularly in thin metal, as cartridge sheets. This metal is sometimes of nearly pure copper, but often of alloy with zinc in considerable amount. Cartridge metal, passing the severest tests, was reported by Capt. Michaelis as failing in firing; later an improvement was observed. Dr. Egleston attributed failure in such cases to several causes, as impurities in the copper, oxidation, overheating, underheating, and over-compression in the rolling mill. Large quantities of gas are sometimes separated from the metal, often many times its own bulk. The stress and flow caused by the presence of this gas may be the most usual cause of loss of strength with time.

Copper is rarely worked in the lathe or by cutting tools; it is soft, yet tough and tenacious, and is easily distorted by the resistance offered to the tool, which it clogs and causes, especially if the latter is sharp and has an acute cutting angle, to chatter and dig into the work. Its peculiar qualities fit it well for working with the hammer, and it is often forged hot, and still oftener worked cold. Pieces are often cast and then hammered into the desired form, or beaten to the required degree of thinness. If, during the process, the metal becomes too hard and brittle, it is annealed by heating and suddenly cooling it.

Joints are made either by "brazing" or "hard-soldering" with an alloy of copper rich in zinc, by rivetting, or by soft-soldering with an alloy of tin and lead.

Copper vessels are usually brazed, and when used for culinary purposes, or when liable to be filled with alkalies or other substances which may dissolve the metal, are tinned. This operation consists in first thoroughly cleaning and brightening the surface by scraping or sand-papering, then washing with a solution of sal-ammoniac, or of zinc in hydrochloric acid, which leaves a clean metallic surface, free from oxide and greasy matter. Tin is then melted in the vessel and rubbed over the whole interior, the surplus finally poured

off, and the polishing completed. Oily and ammoniacal matters, and according to Sir Humphrey Davy, weak solutions of salt, attack copper, as do nearly all acids.

Sheet Copper was formerly much used by engravers, but has been much less generally called for by that trade since other engraving processes have been perfected. Engraved rolls for calico-printing often have their surfaces made of the finest sheet copper, but are sometimes made of the cast metal. Embossing cylinders are made of copper or gun-metal. The patterns are produced either by engraving or by stamping.

Sheet copper is used to some extent, but less than formerly, in lining air-pump cylinders for steam engines and pumps used in mines, where the water is found to seriously corrode iron; but here, as in sheathing ships, alloys with tin or zinc have displaced the unalloyed metal.

The sheet copper found in the market is classed as Brazier's Sheets and Sheathing Copper. The sizes of the sheets are:

SIZES AND WEIGHTS OF SHEET COPPER.

	BREADTH.	LENGTH.	WEIGHT.
Brazier's	2 feet.	4 feet.	5 to 25 lbs. per sheet.
	2½ "	5 "	9 to 150 " "
	3 "	5 "	16 to 300 " "
	4 "	6 "	16 to 300 " "
Sheathing	14 inches.	48 inches.	14 to 34 oz. per sq. ft.

The weight may be approximately computed by multiplying the cubic contents of the mass in inches by 0.3212 to obtain the weight in pounds.

The thickness of sheet copper is often measured by wire-gauge, and the diameter of copper wire is always so measured.

Copper is used to some extent in electro-plating, and is of common use with a slight alloy of hardening metal in coinage; sheet copper is often tinned. Nearly all the copper

used in the arts, however, is alloyed with zinc and tin to form the brasses and bronzes.

When used unalloyed, specifications should call for a tenacity of at least 25,000 pounds per square inch in castings, 35,000 in bars, and 60,000 in wire (5,075, 7,105, and 4,218 kgs. per sq. cm.).

Copper wire is used in enormous quantities in the construction of electric and magnetic apparatus. Its great conductivity, which is six times that of iron, makes it peculiarly valuable for this purpose. Its greater conductivity for heat, also excelling iron two and a half times, has given it value for heating surfaces of steam boilers. Copper "fire-boxes" are often used in locomotives, and copper utensils are of frequent use in minor departments of engineering, as in distillation, and in chemical and culinary operations. It is used to some extent in the sheathing of wooden vessels; but one of its alloys, a special sheathing metal, has now nearly taken its place. The "fastenings" of wooden ships are, in the best practice, always made of copper; it oxidizes very slowly, and its oxide does not injure the timber through which it is driven. Its use unalloyed is far less extensive, however, than when alloyed with other metals.

The steam and feed-water, and other pipes used on ship-board and on locomotives, are often made of copper, as are the staybolts of heating surfaces when the latter are made of this metal. Sheet copper is rolled, for fire-boxes and other purposes, up to 10 feet 10 inches (3.3 metres) long. These sheets must be free from cracks, blow-holes, or scale; and to secure a good surface, the sheets are inspected while going though the rolling mill, and any defects detected are carefully removed by the chisel, or by scraping, before the finishing pass is given. It is even necessary, frequently, to plane the ingots before rolling them.

Fire-box tube-sheets are hammer-hardened, in order that the "expander" used in setting the tubes may not distort the sheet. Hammer-hardened copper, when tested by tension, stretches irregularly, and the hammer-hardened plate may thus be distinguished from plate not so treated; the effect is

also seen in the diminished elongation without much change of tenacity. Moderate hammering, according to Lebasteur, is quite as effective as more severe work.

Copper rods, or bars, are made with the same care, and the same precautions are adopted, as in making sheet copper. If reduced by the wire-drawing process, the reduction must be small at each pass, and the metal should be occasionally annealed, if the reduction is considerable. The maximum reduction in diameter should not exceed $\frac{1}{16}$th inch (0.16 centimetre). Rods intended for fire-box stays are often drilled through the axis of the stay, as a means of detecting fracture; these stays are now sometimes made by rolling up heavy sheet copper on a mandril and then drawing to size.

Copper tubes and pipe are sometimes made by repeatedly stamping disk-shaped ingots under the hydraulic press, and thus gradually changing their form to that desired. Very large quantities of copper are used in coinage.

The consumption of copper in the United States is not far from 50.000 tons * per annum, and a very nearly equal amount is used in Great Britain.

Copper is, when cast, rendered sound and strong by the use of phosphorus as a flux. Abel, in 1860, found that the introduction of 2 to 4 per cent.† produces a remarkably uniform, sound, dense and tough metal, exceeding the strength of ordinary gun bronze by one-half, and attaining a tenacity of 50,000 pounds per square inch (4,218 kilogs. per sq. cm.)

Alloyed with tin to form bronze, and with zinc to make brass, copper has extensive use in all the constructive arts. It is used in alloying gold and silver for coinage, plate, and other similar purposes for which those metals are too soft. The copper usually amounts to about ten per cent. of the total weight.

Copper wire is now extensively used for telegraph and telephone circuits. It is always "hard drawn."

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* *Engineering and Mining Journal*, 1884.

† Construction of Artillery; Inst. Civil Engineers, 1860.

Tin (*Stannum;* Sn.) is less widely and less plentifully distributed than copper, but has probably been as long known and as generally used. In fact, the two metals have always been, as they are to-day, almost invariably used together; and their alloys, the bronzes, have been in general use since the earliest times. The ores of tin are found and worked extensively in Devonshire and Cornwall, Great Britain, and less extensively in Malacca, Banca, Germany, and Australia, in small quantities at Ashland, Alabama, and lately in the Black Hills of Dakota. Banca tin usually commands the highest price; it is known in the market as "Straits Tin."

Tin is found as "stream tin" (cassiterite) in many parts of the United States which are underlaid by the primitive rocks, and the ores are found in small quantities in California and other States west of the Mississippi, in Maine, and in Alabama. It is only worked at Ashland, Clay Co., in the last-named State, and there only since 1883. The tin used in the United States comes principally, via Great Britain, from Banca, Billiton, Cornwall, Australia, and South America. The amount is above 10,000 tons annually.

Tin sometimes occurs in the metallic state, but is generally found as an oxide.

Ores, and Processes of Reduction.—The common ore of tin, cassiterite, stannite, stannic oxide, SnO_2, is a dioxide, and is often called tin-stone or stream-tin. The ore usually contains between 65 and 75 per cent. metal. It occurs in veins traversing the primitive rocks. Much care is demanded in dressing it, and in assorting it into the four qualities usually classed at the mine. The ore is stamped, washed, weathered a few days, calcined, again weathered and washed, and finally smelted in reverberatory furnaces. The tin thus obtained requires refining, which is done as in the working of copper, the melting and poling demanding and occupying five or six hours, and yielding a very pure metal. The blast-furnace is sometimes used instead of the reverberatory, and is said to yield a purer tin.

In detail, the processes of preparation are as follows:

The oxide comes to the metallurgist as "tin-stone," or

oxide, either as "stream tin ore," called often "alluvial ore," or "mine tin ore." The former is usually comparatively clean. The latter is washed, to free it from the earthy matters accompanying it, by stirring it on a grating under a flowing stream; it is then assorted carefully, the stony and useful part picked out and thrown away, the remainder broken, if in large pieces, and reduced to a sufficiently small size to work well under the stamps.

The stamps consist of a series of heavy blocks of wood shod with cast iron, usually weighing 225 pounds (102 kilogrammes) or more, mounted on the lower ends of vertical shafts. They are lifted by cams revolving on a horizontal shaft, which engage lugs secured to the vertical rods. The motive power is either water or steam, and the stamps make fifteen to twenty-five blows per minute. The stamps fall into a trough into which the ore is fed, and as it is pulverized by the blows it is washed out at the side, through a finely perforated screen, by a constantly flowing stream of water.

From the stamps, the fine ore is carried by the current to a succession of settling tanks, in which it collects, while all other and lighter matter is swept away. The "slimes" thus retained are removed, are again washed in a flowing stream of water, and are then sent to the calcining furnaces. These are reverberatory furnaces, in which the sulphur and arsenic are driven out of the pyrites with which the ore is usually contaminated. The addition of common salt aids in this process, by the production of vaporous chlorides.

The ore is now washed once more to remove the sulphate of copper which exists in the mass, and often still again to free it from oxide of iron and other lighter mineral matters, leaving the "black tin" in proper shape for smelting.

The smelting process is conducted in reverberatory furnaces similar in general form and method of working to those used in iron working. The charge of ore, now containing about sixty per cent. tin, and weighing a ton or more, including about twenty per cent. its weight of ground coal and lime, introduced as a flux to remove the silica, is dampened with a small quantity of water and spread upon the hearth.

At a low, and long-continued heat, the oxide of tin gradually becomes deoxidized by the carbon present, and the metallic tin settles in the middle of the furnace, the hearth being slightly dished to receive and retain it. The ore is continually stirred as this goes on, to facilitate the settling of the tin; while the heat is finally considerably raised to produce a fluid slag. The slag is finally removed, and the tin is run off into a reservoir, from which, after the dross has risen to its surface and been skimmed off, the metal is cast in ingots. A portion of the slag is sufficiently rich in tin to be re-worked.

The ingots of tin, made as above, are refined by re-melting and separation from the dross, and then "boiling" in a large refining basin, kept at a moderate temperature, somewhat above that of fusion, by a process resembling in principle the "poling" of copper. The wood is secured in the bottom of the tank under the tin, and the steam and gases rising from it as it chars beneath the molten tin, cause the foreign materials to separate and rise to the surface.

This process being completed, the tin is again cast in ingots; the quality of the metal being determined, not only by the extent to which the purification has been carried, but on the part of the pool from which the ingot is cast. The upper part is purer than the lower, and yields "refined tin," while the lower portion is ordinary "block tin"; they should contain from 0.985 to 0.998 pure tin. The lowest part of the molten mass in the basin is reserved for further refining.

A small blast-furnace is sometimes used, as in Saxony, in reducing the ore; but it is a wasteful process. The fuel is charcoal, and the flux is either siliceous or calcareous, according as the ore contains an excess of basic or acid constituents.

Commercial tin is never pure. Chemically pure tin has a specific gravity of 7.28 to 7.4, according to the method of preparation, the purest being lightest. Its atomic weight is 116; color white, with a tinge of yellow; it possesses a peculiar odor; it oxidizes with difficulty, and when bent emits the crackling sound known as the "cry of tin." It has little tenacity, considerable ductility, and greater malleability.

The coefficient of expansion is 0.000023; its melting point is 443° Fahr. (232° Cent.); specific heat, 0.0562; latent heat of fusion, 14.25. It boils at a white heat; its conductivity is low.

Tin oxidizes very slowly in the air at ordinary temperatures, but burns quite freely at a white heat and with a white flame. Exposed to severe cold it becomes crystalline and friable. Its principal uses are in the making of alloys with copper, zinc, lead, etc., and in the manufacture of "tin-plate."

The yellow oxide is used for polishing metals, such as steel cutlery and glass. The white oxide is used in making a white opaque glass generally known as "enamel."

This metal is readily rolled into very thin sheets, known as tin-foil, and drawn into tubes and into fine wire. It resembles zinc in its change from great ductility at the boiling point of water, to equal brittleness at about 400° F. (204° C.). It then melts a few degrees above the latter temperature, as already stated.

The following is a complete analysis, made at the request of the Author, of Queensland tin:

ANALYSIS OF "QUEENSLAND TIN."

	Per cent.		Per cent.
Lead	0.165	Antimony	none.
Iron	0.035	Bismuth	"
Manganese	0.006	Nickel	"
Arsenic	trace.	Cobalt	"
Copper	none.	Tungsten	"
Zinc	"	Molybdenum	"

Kerl * gives a set of analyses, thus:

KIND.	BANCA.		BRITISH.		PERUVIAN.		SAXON.	BOHEMIAN.	
Elements....	1	2	1	2	1	2		1	2
Tin	99.961	99.9	99.96	98.64	93.50	95.66	99.9	99.59	98.18
Iron	0.019	0.2	.....	.....	0.07	0.07	.....	.....	.....
Lead	0.014	.....	.....	0.20	2.76	1.93	.....	.....	.....
Copper	0.006	.....	0.24	0.16	.....	.....	.....	0.406	1.60
Antimony	.....	.....	.....	.....	3.76	2.34	.....	.....	.....
Bismuth	.....	.....	.....	.....	.....	.....	0.1	.....	.....

* Metallhuttenkunde, 1873.

Grain tin is made by heating ingots to a temperature at which they become brittle and breaking them up by dropping them on the floor.

MANUFACTURED TIN is found in the market in nearly every form in which iron and copper are sold.

Tin-foil is made by rolling into plates and sheets, then heating, doubling, and again rolling, and repeating the latter processes until it is sufficiently thin for use as desired. It is sometimes rolled down in a compound sheet composed partly of lead; and it is often alloyed with lead to make thin sheets and other forms. Tin-plate is made, as described in the preceding volume, by tinning sheet-iron, and consists principally of the latter metal. Copper, lead, and zinc are sometimes tinned. Brass pins are tinned by dipping in a solution of the chloride or of the oxide; the other metals are sometimes similarly tinned.

Unmanufactured tin comes into the market as "block tin," as "grain" tin, and in small bars or "sticks." Block tin is cast in ingots or blocks in moulds of marble; grain tin is made by heating these ingots until very brittle, and then breaking them up on stone blocks; it is sometimes granulated by melting and pouring into water.

The production of tin has been enormously increased during late years by the increased demand for tin-plate, which is due to the growth of the "canning industries" and the roofing business. The consumption now exceeds a quarter of a million tons per year.

Sheet tin, or tin-foil, is often no more than one-thousandth of an inch (0.00254 cm.) in thickness. The foil is used for wrapping tobacco and other materials which are to be protected from the action of the atmosphere. Thicker sheets are used in "silvering" mirrors by amalgamation with mercury, and for making amalgam and for other purposes connected with the generation and use of electricity. Pure tin is used in making some tin vessels, as dyers' kettles. Its cleanliness and innocuous qualities make it valuable for tinning culinary utensils. The tubes are used sometimes alone, and often as a lining for lead pipe, in the supply of water to

houses. The wire is very ductile and moderately tenacious, and has the perfect inelasticity exhibited by tin in all its forms.

Tin is very extensively used alloyed with lead, in pewter and Britannia metal, and sometimes with a little copper as a hardening or "temper."

The evidence lately discovered of the existence of an extensive region, bearing tin, in Dakota, according to the report of Professor Blake,* and of other deposits in Alabama, lead to the expectation of a large future development of this industry in the United States.

Of the whole product of the world, over 15,000 tons per annum are used in Great Britain, probably nearly as much in the United States. Cornwall supplies above 10,000 tons per annum, Banca is producing large quantities, and Australia is rapidly approaching that district in its production. The use of tin for "tin-plates"—sheet iron tinned on both sides—is a very great proportion of the total. Good "tin-plate" is plated with the best tin, while the cheaper, or "terne," plates are plated with cheap alloy. Good tin-plate is distinguished by the thickness, evenness, and brightness of the coating of tin, the absence of dark spots produced by imperfections in the coating and of roughness due to the incomplete covering of the rough iron surface. "Pin-holes" in the coating often indicate a low grade of iron in the plated sheet. The iron should be good "charcoal iron," but is often "coke iron." The cheaper grades are as suitable for many purposes as the more expensive.

Zinc in the metallic state was not familiar to the ancients, although they were accustomed to use its ores in the manufacture of brass. The alloy was used in coins occasionally; the Greek and Roman coinage was, however, principally bronze. Zinc was probably discovered, five hundred years ago, by Albertus Magnus, and by him called *marchasita aurea;* its modern name was first given by Paracelsus in the middle of the sixteenth century. It became a regular article of manufacture about 1720, in Germany, and in England

* *Engineering and Mining Journal*, 1883.

fifteen or twenty years later; the ore generally reduced was calamine, and the process was one of distillation. The metal had already been smelted in the East Indies. It has been regularly manufactured in the United States since about 1850, first at Bethlehem, N. J., and later in a number of other localities. The city of St. Louis, alone, supplies the market with fifteen tons per day. The whole product for the United States was, in 1883, about 40,000 tons (or tonnes, nearly).

Zinc ores were known to the ancients, and were used in the manufacture of brass long before the art of reducing them was discovered. The alloy was made by smelting together the ores of copper and zinc. The metal became known about 1600, but was little noticed until after Hobson and Sylvester discovered, in 1805, that it becomes ductile and malleable at about 300° F. (144° C.), when it was brought into the market in competition with lead. It has since been extensively used for sheathings, roofing, culinary, and other vessels, architectural ornaments, etc. The oxide is extensively used as a substitute for white lead.

Ores of Zinc occur abundantly in the United States, the best being obtained in New Jersey, Pennsylvania, and Virginia, and in a line of deposits running through West Virginia and the Middle States, across to Illinois, Missouri, and Kansas, and north into Wisconsin. Large quantities are mined in Missouri and other parts of the country. They are mined extensively in Europe. Calamine and blende are the ores principally used in the production of the zinc of commerce.

These ores are the carbonate known as calamine, the silicate, or siliceous calamine, the sulphide, or blende, and the oxide, or red ore.

The latter is given its color by the oxides of manganese and iron which are present with the zinc. It is the common ore of New Jersey. Calamine is also found in the United States, near the red ore. It is a common ore in the North of England and in Scotland, in Belgium, Silesia, Spain, and Sardinia. It is an impure carbonate, having a peculiar columnar structure, a dirty red color, and moderate cohesion.

It often contains lead, iron, manganese, and cadmium and rarer metals.

When raised from the mine, the ores are carefully picked over, and the gangue and lean ores removed as completely as possible. They are next broken to small fragments or powder under stamps, and washed very thoroughly.

They are calcined and smelted, the calcination rendering them porous and more easily reducible by driving out moisture and carbonic acid. The process is generally conducted in reverberatory furnaces, but sometimes in kilns.

In smelting, the ore is mixed with half its weight of any cheap form of carbon, the two materials being well ground and mixed, and is reduced at a high temperature in retorts or muffles, usually three feet long and eighteen inches high, a half-dozen being heated in a single furnace. The reduced metal passes off in the state of vapor, condenses as it issues through a properly formed channel, and flows into the moulds placed to receive it. The process is therefore one of distillation.

Two processes are in use—the Belgian and the Silesian. In the former the distillation is carried on in cylindrical retorts, four or five diameters in length, put up in "benches," which consist of forty or fifty, or even more, set in several rows, one above another, within a furnace stack, with one end depressed and accessible from the front. Two or four furnaces are often built in one structure, and their products of combustion are led to a single chimney. The upper rows of retorts are charged with about sixteen pounds (7.26 kilogrammes), and the lower with fifty per cent. more ore, the charge being first moistened to prevent the formation of dust. The furnaces and retorts are heated separately, and after three or four days' heating the former, the latter are introduced. The open end of the retort is closed by a fire-clay plug to which an iron funnel-shaped cap is fitted to conduct the distilled zinc away, while acting also as a condenser. Every two hours these are removed and cleared out, the zinc collected in them thrown into a ladle, and the unreduced oxide found with it is re-worked later. The retorts are re-

charged every twelve hours, and the furnaces are only stopped for repairs about once in every two months. The zinc is poured from the ladle, when filled, into ingot moulds.

In the Silesian process, the distillation is carried on in ovens or muffles, which are better calculated to bear high temperatures, and in which, therefore, the work can be more perfectly done.

The distilled zinc runs down an iron tube, which is the condenser, into a small reservoir at the mouth of the oven. Thirty-two are set in a furnace. They are re-charged once a day. Re-melting is carried on in clay-lined iron crucibles or kettles. The fuel consumed in these processes is from about six times the weight of ore in the best examples of Belgian work, to twelve or fifteen in the Silesian furnaces.

Zinc ores are often found to contain lead, and their treatment by usual processes is somewhat difficult. Thus Chenhall * gives:

COMPOSITION OF ZINC ORES.

	CONSTANTINE.	CAVALO.	BLUESTONE.	AMERICAN.
Zinc	10.64	13.40	29.28	27.20
Lead	4.81	17.14	12.90	12.00
Copper	1.35	0.44	0.65	0.20
Silver and Gold	0.04	0.06	0.03	....
Sulphur	26.85	15.37	22.14	....
Iron	19.93	4.98	7.16	....
Alumina	2.33	1.02	....	....
Magnesia	....	0.22	....	....
Barium sulphate	....	35.04	....	....
Silica	26.48	11.19	26.84	....
Arsenic	0.65	0.13	0.15	....
Lime	0.60	....	0.84	....
Sulphuric Acid	3.53	....	....	....
Antimony	0.02	....	....	....
Oxygen and loss	2.77	1.01	1.01	....
	100.00	100.00	100.00	....

These ores are treated by the Parnell process of dissolving in sulphuric acid, and decomposing the sulphate by heating

* Proc. British Institute Civil Engineers; 1882–3; Part iv.

it with the sulphide. The loss is reported to be, for lead ores, which are similarly treated, three per cent.

Commercial zinc thus prepared usually contains some lead, and may contain a considerable amount. Where needed pure, it should be very carefully selected by analysis.

Metallic Zinc is a bluish white metal known to the trade as "*spelter.*"

Its atomic weight is 65. It is rather brittle, and can be rolled satisfactorily only when heated somewhat above the boiling point of water. When pure, it can be worked, with care, into bars or sheets at ordinary temperatures. After passing the boiling-point, it again gradually loses its ductility and malleability, and can be powdered readily at a temperature somewhat below the red heat.

The rolling of this metal was at first accomplished with very great difficulty, from the fact that its malleability is confined to very narrow limits of temperature. For this reason it is always an operation only entrusted to experienced hands. The most suitable temperature is about 120° Cent. (248° Fahr.), and this must be maintained throughout the process. Below this point the metal opposes too great a resistance, and must be re-heated; above this point it becomes brittle; at 200° Cent. (390 Fahr.), it can be brayed in a mortar.

Zinc should be re-melted before being rolled into sheets. The heat of fusion varies between 400° Cent. and 500° Cent. (750° Fahr. and 930° Fahr.). Re-melting is generally performed in a reverberatory furnace to cleanse the zinc of impurities. The thickness of the ingots must vary with the final dimensions required; this renders re-melting indispensable.

The re-melted plates are first roughed down or rolled between heavy rolls, and after being cut down to a fixed weight, are taken to the finishing train, where the rolling is completed. There are thus two distinct operations—the roughing down and the finishing. Between the two, the sheets are re-heated in annealing boxes placed upon the melting furnace. Each operation gives rise to a production

of scrap, which is more or less large in amount according to the quality of the metal and thickness of the sheet. This scrap, and all defective sheets, are re-melted with the ingots from the foundry.

The fact that zinc, heated to a temperature exceeding the boiling point of water, becomes malleable, was discovered about the year 1805, and rolled sheet zinc then soon made its appearance in the market, and was used to some extent as a roofing material.

Zinc is used extensively in the form of sheets for roofing, sheathing of iron ships, domestic utensils, etc., etc. Very large quantities are used by the engineer in the brass alloys and in the surface-protection of sheet-iron. It unites readily with the other useful metals to form alloys, which are usually characteristically different from their constituents. The principal of these alloys are the brasses, or alloys with copper. The metal is also often mixed in small proportions with the bronzes, or copper-tin alloys, to form the copper-tin-zinc ternary alloys often used in machine construction. Of the world's product of this metal, amounting to above 200,000 tons, the United States produces twenty per cent. Belgium and Germany make two-thirds.

Zinc sheets of standard dimensions have the following weights:

THICKNESS AND WEIGHT PER SQUARE FOOT.

Inch.	Inch.	Inch.
.0311 = 10 oz.	.0534 = 14 oz.	.0686 = 18 oz.
.0457 = 12 oz.	.0611 = 16 oz.	.0761 = 20 oz.

Cast zinc, as well as rolled, is often used in the manufacture of ornamental work; it takes the impression of the mould as sharply as good foundry iron, and is especially liked for small work.

A prize offered in 1826 by the Society for Advancement of Industry in Prussia, led to the discovery, by Krieger, of Berlin, that hollow ware can be cast in zinc, and, by Geiss, that it would make good architectural ornaments. An exten-

sive consumption of the metal for these purposes at once arose, and the applications of zinc in these directions are becoming rapidly more general. It is largely used in decoration, as a substitute for bronze, and to a considerable extent in the construction of large statuary; in this case, however, the mass is usually built up of smaller parts soldered together. Berlin has been the head-quarters of this industry.

Zinc castings made at a high temperature are brittle and crystalline; when cast at near the melting point, they are comparatively malleable. It is hardened by working, and must be occasionally annealed.

The value for sheathing and for work exposed to the weather, arises from the permanence and impenetrability of the coating which forms over its surface—a basic carbonate.

Zinc is the most strongly electro-positive of the metals of commerce, and is almost exclusively used as the perishable element in voltaic batteries.

It has a specific gravity of 6.9 to 7.2, melts at 770° F. (410° Cent.), and boils at 1900° F. (1040° Cent.); its vapor burns readily with a bluish-white flame, forming the white oxide.

The salts and the higher oxide of zinc are extensively used in the arts, especially in making paints and dyes. The chloride is used in large quantities as a preservative of timber and as a disinfectant.

Rolled zinc is made very much as sheet lead or sheet copper is made; but its temperature must be kept at a little above the boiling point of water, to secure the necessary malleability, and it must also be free from alloy. It is freed from its most usual constituent, lead, by re-melting the spelter, as received from the furnace, on the hearth of a reverberatory furnace which has a gradual slope terminated by a basin, into which the melted metal flows, and in which the zinc and lead separate, the lead settling to the bottom, while the zinc lies on the top. The zinc is ladled out and cast into ingots for the mill.

These ingots are warmed to the proper temperature, and then rolled into sheets, and sometimes into bars, between

rolls kept heated by the passage through them of steam of moderate pressure.

Galvanized iron is sheet iron covered with a coating of zinc by immersion in molten zinc.

Zinc is produced in the United States to the amount, annually, of about 40,000 tons (1883), and the production is rapidly increasing. At least one-half comes from Illinois, one-third from Missouri, and nearly as much from Kansas. New Jersey supplies zinc of excellent quality, and furnishes all that is exported, sending abroad over 40,000 tons of ore. The gas-furnace of Siemens is now adapted to smelting zinc, and is coming into general use in consequence of its cheapness of operation and manageability. The known deposits of zinc are being rapidly worked out.

The importations of foreign zinc into the United States are more than equalled by the export of special grades of American zinc to Europe, where the metal is much sought on account of its high value for the manufacture of military rifle cartridge cases.

The amount of coal used for one pound of zinc is the following at the different works, the Eastern works using anthracite principally, and the Western works using bituminous coal:

	FUEL.	REDUCTION.	TOTAL.
Passaic	4.5	1.3	5.8
Bergen Point	5.5	1.9	7.4
Lehigh	4.5	1.7	6.2
Carondelet	4.4	1.2	5.6

The yield of zinc is stated to be

Lehigh, for calamine	73.5 per cent.
Lehigh, for blende	70.0 "
Passaic, for calamine	80.0 "
Martindale, for blende and silicates	73.0 "
Carondelet, for silicates	76.80 "

Of the whole quantity consumed in the United States in 1883, about ten per cent. is used in galvanizing wire.

Lead (*Plumbum;* Pb.) is a bluish-white, lustrous, inelastic metal, so soft that it may be easily scratched with the finger-nail. It has too little tenacity to be readily drawn into fine wire, although some lead wire is found in the market. It is very malleable, and is very extensively used in the forms of sheet-lead and lead-pipe. It is very heavy (S. G. 11.4), and is easily fusible, melting at 620° F. (327° C.); it absorbs, in fusing, 5.4 metric thermal units per kilogramme (9.8 B. T. U.). Its specific heat is 0.03 at low temperature, and 0.04 near the melting point. The coefficient of expansion is given by Calvert and Johnson at 0.00003. It is a very bad conductor of both heat and electricity. At high temperatures it becomes slightly volatile; in this respect and in changing in character from ductile to brittle as the melting point is approached, it resembles zinc somewhat.

Oxidation occurs but slowly in dry air, and the oxide forms a protecting coating over the metal. When exposed to moist air containing carbonic or acetic acid, however, oxidation progresses rapidly. Lead is readily dissolved in water containing carbonic acid or salts of nitric acid; the solution is poisonous, as all the salts of lead are cumulatively poisonous.

Lead oxides are of great value in the arts. "Red lead," or minium (Pb_4O_5), is used, mixed with drying oils, as a pigment, and by the engineer as a cement, in the latter case often mixed with "white lead," a basic carbonate [$2PbCO_3Pb(OH)_2$], which admixture gives greater hardening and cementing power; this quality is often still further improved by the addition to the cement of red and white lead, in oil, in equal parts, of several times its weight of borings of iron with a little sal-ammoniac and sulphur. Red lead is much used in the manufacture of flint glass.

Lead compounds are easily identified by the formation of the yellow oxide in the reducing flame of the blow-pipe. Lead salts in solution give a black precipitate when exposed to the action of sulphuretted hydrogen.

Lead was known, but was of little importance in the earliest historic times. It is supposed to have been discov-

ered later than either copper or tin. It was the custom, apparently, among the Hebrews and their contemporaries, to engrave records of importance, and which were desired to be made permanent, upon tablets of lead with an iron stylus. The Phœnicians used the metal in weighting anchors, and sold it to the Greeks and the Egyptians. It was used by the Babylonians, according to Herodotus, in securing iron cramps in masonry, probably in the same manner as is usual in modern engineering.

The Ores of Lead are galena or the sulphide, and the carbonate. Nearly all the lead of commerce is obtained from galena, which consists of eighty-seven per cent. lead, nearly, when pure, and 13 per cent. sulphur; it nearly always contains silver, sometimes in quite large amounts, varying from a fraction of one per cent. up to fifty per cent.; arsenic, copper, iron, and zinc. The ore is sometimes worked for its silver. Galena is worked in Saxony and Bohemia, in England, Spain, and the United States; it is usually found in the palæozoic rocks. The ores worked in the United States generally contain comparatively little silver, and are quite pure. They are found principally in the valley of the Mississippi. Enormous deposits exist in Missouri, Iowa, Illinois, and Wisconsin, in crevices and pockets in those lower Silurian rocks which have lately been distinctively known as the galena limestone. These deposits have been worked only from about 1820, although the existence of the ores had been then known more than a century. The ores of lead occur all through the Alleghanian districts of the eastern United States, but none are profitably worked.

Lead ores are now often smelted in furnaces of the Rachette type, *i.e.*, having a rectangular form and widening section from bottom to top. These permit the use of a low pressure of blast, and comparatively unlimited magnitude of charge. The fuel is usually charcoal or coke, or both, the flux is iron and limestone, or sometimes silica, and the ore is broken to the size of the fist or of an egg. The ore is often first roasted. The total fuel used amounts to from fifteen to twenty-five per cent. of weight of charge.

The Smelting of Galena is performed in a reverberatory furnace, first roasting it, usually adding a little lime, until it is largely converted into lead sulphate. An increase of temperature of furnace with an oxidizing flame drives off the sulphur in the form of sulphurous acid, and the reduced metal is tapped off. Some of the lead is volatilized, and is condensed in the flues or in a vacuum chamber, constructed for the purpose, in which it meets with a shower of water.

Antimony and tin, when present in objectionable proportions, are oxidized by exposing the molten lead, in shallow pans, to the action of the air. Silver is removed, usually, by the Pattinson process of concentration, by melting, agitation, and slow cooling, with repeated separation of the crystallizing metal which contains little silver, from the more infusible portion which is richer in the precious metal. The final product is subjected to the action of the air at high temperature, which oxidizes the lead and leaves the silver in the metallic state.

The lead-smelting process is thus largely, like the process of reducing copper, one of desulphurization. The preliminary roasting of galena converts a part into oxide of lead, the metalloid passing off in sulphurous acid, while another portion becomes a sulphate. The whole mass is then melted, the sulphur all passing off in sulphurous acid, and the metallic lead is left behind. This is done on the basin-shaped hearth of a reverberatory furnace, which is about six feet (1.8 metres) wide and 8 feet (2.44 metres) long, and is lined with slags melted down in place. The tap-hole for the slag is above that for metal. The process of smelting is conducted in four operations or "fires."

The lead tapped off at the first melting of argentiferous ores is richest in silver. As soon as it is out of the furnace a second charge is thrown in and roasted; the dross from the preceding charge is added.

Some lead is reduced and is tapped off after an hour or more, and the remaining ore is, in the course of about two hours, converted into oxide and sulphate.

The temperature of the furnace has been, up to this

period, kept below the red heat, in order that the ore may not melt down and the desired change thus be checked. The heat is now increased to a full red, and the reaction of the oxide and sulphates present upon the sulphide, leads to the reduction of the lead, which runs off freely. This process occupies about an hour, and the temperature of the furnace has been alternately raised and depressed to facilitate the separation of the metal; a little lime being added, also, to flux the ore.

The temperature is now again raised for another hour; more lime is added, and further reduction occurs. Finally, the furnace is heated to its maximum temperature, and held at this heat for three-quarters of an hour or more, when the lead is tapped off, the slags hardened with lime, and reduction is complete. The whole process has occupied five hours or more. The fuel consumed amounts to something more than one-half the weight of the ore smelted.

The slag is still rich in lead, and is again worked separately.

The molten lead tapped off is often refined, as is done in purifying tin, by the use of sticks of wood in the basin. It contains a considerable amount, often, of silver, copper, antimony, and iron, amounting sometimes to several per cent. This is partly removed by the process of "softening," which consists in running it into a reverberatory furnace, having for its hearth a shallow basin, and there oxidizing out the impurities by exposing it to the oxygen-laden gases passing over it. The process of refining is sometimes hastened by adding a quantity of the nitrate and the carbonate of soda with lime, which supplies the needed oxygen.

When rich in silver, Pattinson's process is adopted. This consists in melting in a series of basins, in which the metals gradually separate. Lead crystallizes at a lower temperature than the alloy, and the molten metal being allowed to cool slowly, crystals of comparatively pure lead are formed, which are separated from the remaining mass which is richer in silver, and are transferred from one melting pot in a series to another; the lead richer in silver being gradually separated until that to be sent to market contains little to pay for

further working. The melting pots are set side by side, and the purer lead is transferred from pot to pot in one direction, while that containing silver is similarly transferred in the reverse direction, until the pots at the extremes of the series contain, the one nearly pure and marketable lead, while the other contains so much silver that it can profitably be worked to recover it.

Commercial Lead.—The lead is run into "pigs" about 3 feet (0.9 metre) long, usually weighing about 150 pounds (70 kilogs.). Spanish "pigs" weigh 112 pounds (50 kilogs.). A "fodder" is 8 pigs.

Pig-lead is rolled into sheets 6½ to 7½ feet (2 to 2¼ metres) wide, 30 to 35 feet (9 to 11 metres) long, and sent to market in rolls. The weight runs very nearly six pounds per square foot for each 0.1 inch thickness (120 kilograms per square metre per centimetre in thickness). Sheet-lead is extensively used for tanks, sheathing, etc., and sometimes, although less than formerly, for roofing. Lead-pipe is made as below by forcing lead through an orifice, the size of the pipe to be made, over a former which gives it the required internal diameter.

Lead shot is made by dropping the molten metal from the top of a shot-tower of such height that the globules of the leaden rain thus produced may cool and become solid before striking the water in a tank at the bottom, placed there to receive it.

Lead pipe is now made by a peculiar process called "squirting"; it was formerly made by a process of "drawing" through dies. In the modern process, the lead is melted in crucible, or iron pots, and then carried to a compressing chamber fitted with a plunger which is driven by hydraulic pressure. The lead is allowed to solidify and cool to about 400° F. (204° C.). The ram is then forced down upon it, and, at a pressure of a ton and a half or more per square inch, the lead flows freely from an orifice in the bottom of the chamber, and around an iron core attached to the plunger, thus taking the size desired, and issues in the form of a pipe of a length determined by the relative capacity of the chamber and section of pipe.

Bar lead and lead wire and rods are made in the same manner, but dispensing with the core on the plunger. The compressing chamber is sometimes attached to the hydraulic press plunger, and rises against a fixed plunger in which is the orifice of issue, while the core is fixed in the compressing chamber. This arrangement is more convenient and causes less frictional resistance. Tin-lined pipe is often made.

The alloys of lead will be referred to later. The oxides and salts have great value in the arts.

White lead, the carbonate of lead, is made by exposing sheet-lead to carbonic acid and moisture. The lead is coiled up in pots, piled in heaps and covered with spent tan-bark and horse-dung. A little acetic acid, in each pot, attacks the metal, forming the acetate, which is then altered into carbonate by the carbonic acid generated in the hot-bed. It it used extensively in making paints.

Red lead is produced by heating the protoxide in the presence of oxygen and thus converting it into the peroxide.

Litharge is made by similarly acting upon the metallic lead and thus forming the protoxide. It is used as flux, as a constituent of cement and in the manufacture of red lead and of glass.

The salts of lead are much used in medicine and to a considerable extent in dyeing. They are all poisonous.

Lead is now produced in the United States at the rate (1884) of about 150,000 tons annually, and the production is increasing at the rate of ten per cent. or more a year. But little is imported. Of that produced in the United States, Utah yields about 20 per cent., Nevada, 6 to 8 per cent., Colorado, over one-third, principally from Leadville, and Missouri and Kansas 15 per cent.

Great Britain produces very nearly as much as the United States, reducing Spanish and other imported ores, which are principally argentiferous. Spain exported nearly as much more, and Germany quite as much.

Antimony (*Stibium; Sb.*), is a grayish white, crystalline and lustrous metal, moderately hard, extremely brittle, of inferior tenacity and has a peculiar taste and odor. It

melts at a low red heat, 840° F. (450° C.), and may be distilled at a white heat in an atmosphere free from oxygen. It does not oxidize in dry air at ordinary temperatures, but takes up oxygen slowly in cool, moist air, and rapidly when hot. It expands while solidifying, like iron. Its specific gravity is 6.7.

The most common ore is the sulphuret, which is found abundantly in Borneo and in considerable deposits in England, France, and Hungary, and also in California. It is reduced by roasting to expel the sulphur. The salts of antimony are poisonous.

The metal is a bad conductor of heat and electricity, and is used, with bismuth, is making thermo-electric piles. Its principal use is in the manufacture of alloys, as britannia metal, type metal, pewter, specula, etc. It expands when solidifying from fusion. It is rarely used alone.

Antimony is found in abundance in the Rocky Mountain section of North America, and especially in California and Nevada. The ore is usually a crude sulphuret, containing, often, some bismuth and a little silver. It is smelted at several points and sold in the eastern markets for use in making type metal, britannia ware, and babbitt metal.

Gray antimony was used by the ancients for coloring the hair and eyebrows.

Bismuth (*Bi.*; atomic weight, 208) is a brittle, pinkish white, heavy, useful metal, having some resemblance to antimony. It has a specific gravity of 9.8 to 9.9. It expands on solidifying, at a temperature of 500° F. (260° C.). Its coefficient of expansion is 0.00134; specific heat, 0.0305. It crystallizes with remarkable facility. It may be distilled at a high temperature. It is very diamagnetic. Its principal use is in making alloys.

The metal is obtained either by reducing the sulphide or, oftener, by purifying native bismuth.

Its oxides and salts are used in medicine, and in the arts to a moderate extent, only, almost invariably alloyed with other metals.

Commercial bismuth contains many impurities, which are

removed by fusion with nitre. Chemically pure bismuth is obtained by precipitation, by dilution of its solution in nitric acid. The bismuth of commerce comes principally from Germany and Bohemia, and some from Peru. Deposits of oxides and sulphides have been found in Utah.* The quantity mined is not great and the demand is small, not more than ten or fifteen tons being used in this country annually. It has about one-eighth or one-tenth the value of silver.

Nickel (*Ni.*; atomic weight, 58.8) is a bluish, nearly silver white metal, having high lustre, considerable ductility and malleability, and closely related, chemically, to iron and cobalt, which metals are often associated with it, in nature. It has about the hardness of iron, but is heavier, having a specific gravity of 8.3 to 8.9, has about equal fusibility, but is far less subject to oxidation and corrosion. Its oxide is white and defaces the polished metal comparatively little, and is easily removed. Nickel can be either cast or forged; but it is generally used in making alloys or in plating more oxidizable metals. It is magnetic, although much less so than iron.

The Ores of Nickel are the arsenide, which is by far the most common, and is known to the miners as kupfernickel, the sulphide, the sulphate, and the silicate. Nickel ores are found in France, Sweden, Cornwall, Spain, Germany, New Caledonia, and in Oregon and other localities in the United States, Pennsylvania supplying the greatest quantity. The ores are reduced by fluxing with chalk and fluor-spar, if arseniated, or by roasting and then reducing with charcoal and sulphur to the state of sulphide, and then by double decomposition with carbonate of soda, obtaining the carbonate, which is finally reduced with charcoal. The metal was discovered and the ore reduced as early as 1751 by Cronstadt.

Uses of Nickel.—Nickel-plating is a very important industry and is very extensively practised in the manufacture of small articles.

The sheet-nickel of commerce is as thin as 0.01 inch (0.025

* *Polytechnic Review*, April, 1876.

cm.), and the wire is nearly as fine. It can be welded, with care, and can be forged like iron.

Nickel coinage was commenced, about 1850, by Switzerland, and in the United States in 1857. This application, and nickel plating by electrolytic action, absorb enormous quantities. The working of this metal has been most extensively carried on in the United States by Mr. J. Wharton, at Camden, N. J., from sulphuretted ores mined at Lancaster Gap, Penn. Sheets have been produced 6 feet (1.8 m.) long and 2 feet (6.1 m.) wide.

Dr. Fleitmann's discovery, that a small dose of manganese added to the molten charge, when ready to pour into the moulds, renders the nickel sound, strong, malleable, and ductile, has greatly cheapened, as well as improved, the product. Fleitmann has welded together iron and nickel, and steel and nickel.

Nickel is principally used in the arts in the manufacture of hollow ware which is to be plated with silver, as practised by Gorham, and for vessels of nickeled iron; the latter are less liable to injury than when the nickel is deposited by electrolysis. Iron thus plated with nickel can be worked with nearly the same facility as either metal alone.

Commercial nickel often contains iron. Canadian (Quebec) ores contained,* in the garnet, calcite, 50.40; chromite, 6.87; chrome garnet, 49.73, and in pyroxene, silicon and alumina, 50.60; iron oxide, 8.73; magnesium and calcium oxides, 35.90; water, 5.83. The reduced ore gave: iron, 71.84; nickel, 22.70. The slag contained no nickel.

Commercial nickel contains, usually, measurable amounts of carbon, silicon, iron and often cobalt.

The nickel plates now largely used as anodes for nickel plating are prepared by fusing commercial nickel, generally with addition of charcoal, and casting in suitable form. The subjoined analyses by Mr. W. E. Gard,† of such plates, show that silica may be reduced and retained as silicon, and that a considerable amount of carbon may be present:

* "Nickel Ores"; W. E. Eustis. Trans. Am. Inst. Min., Eng.

† *Am. Journal of Science and Art*, 1878.

	NO. I.		NO. II.		NO. III.	
	a.	*b.*	*a.*	*b.*	*a.*	*b.*
Carbon	.530	.549	1.104	1.080	1.900	1.830
Silicon	.303	.294	.130	.125	.255	.268
Iron	.464	.463	.108	.110	.301	.318
Cobalt	.446	.438	trace	....	trace	....
Sulphur	.049	.057	.266	.340	.104	.096
[Nickel]	98.208	98.199	98.392	98.345	97.440	97.488
Total	100.000	100.000	100.000	100.000	100.000	100.000

No. I. was American nickel, manufactured and cast by Jos. Wharton, at Camden, N. J. A careful examination by means of Marsh's apparatus showed not the least trace of arsenic or antimony. No. II. was a sample taken from a cast nickel anode used by a nickel-plating establishment in New Haven. No. III. a sample taken from the same anode after it had been used in the plating bath until upward of half its weight had been removed. Solvent action had extended quite through the plate, leaving as usual a porous flexible mass retaining its original form. A comparison of Nos. II. and III. shows that under galvanic action the carbon, silicon, and iron of the anode dissolved relatively slower than nickel, while the reverse happens with sulphur.

Aluminum; or, **Aluminium** (*Al.*; atomic weight, 27.5), is a white silver-like metal, very malleable and ductile, a good conductor of both heat and electricity, uniting with oxygen only with great difficulty, and therefore little liable to corrosion either by exposure to air or to the action of the oxygen acids. It dissolves freely in hydrochloric acid and in solutions of the alkalis. It is remarkable for its lightness; its specific gravity being 2.6 to 2.7. The salts of this metal are not expensive, and are used in large quantities in the arts; the sulphate, alum, is the most useful, and finds its most important applications in dyeing and calico printing. The alloys of aluminium are very valuable. Its remarkable lightness, combined with its strength, make it useful as a

constituent of those alloys in which strength and lightness are the needed qualities.

This metal was discovered by Wöhler, in the year 1827, and by him obtained in considerable quantity, twenty years later, by reduction with sodium. Deville obtained it in ingots on a commercial scale, and the metal rapidly became familiar to chemists. Rose, in 1855, found that it could be obtained from cryolite, in which it exists as a fluoride, by reduction with sodium. Reduction with carbon or hydrogen has not succeeded. Cowles' process of reducing compounds of aluminium in the "electric furnace" produces the metal and its alloys at far less expense than earlier methods, and has introduced a large variety of alloys into the market and at moderate cost. Sulphuretted hydrogen gas, which readily tarnishes silver, forming a black film on the surface, has no action on this metal.

Next to silica, the oxide of aluminium (alumina) forms, in combination, the most abundant constituent of the crust of the earth, in the form of hydrated silicate of alumina, clay. Common alum is sulphate of alumina combined with another sulphate, as potash, soda, etc. It is much used as a mordant in dyeing and calico printing, also in tanning.

Aluminium is of great value in mechanical dentistry, as, in addition to its lightness and strength, it is not affected by the presence of sulphur in the food. Dr. Fowler obtained patents for its combination with vulcanite as applied to dentistry and other uses. It resists sulphur in the process of vulcanization so perfectly as to make it an efficient and economical substitute for platinum or gold.

The metal, aluminium, is distinguished from other white metals by its peculiar gray-white color, differing from both zinc and tin, and especially its remarkably low density, possessing as it does, but one-third the weight of copper, one-fourth that of silver, and one-eighth that of gold. It has a pleasant metallic ring when struck, and confers a beautiful tone when introduced into bell-metal. Deville made a bell of but 44 pounds (20 kilogs.) weight, which was, however, one and a half feet in diameter (½ metre), and exhibited an

exquisite timbre; it was presented to the Royal Society in 1868.

It is sufficiently malleable and ductile to permit its being rolled into thin sheets and drawn into fine wire. Its melting point is at, or near, 1,300° F. (700° C. nearly), between the fusing point of silver and zinc, and it does not evaporate at any temperature yet observed. The metal may be worked cold, like copper or soft brass, and may be coined perfectly and easily. Oxidation occurs very slowly and it retains a polish as well as silver. It has often been proposed for use in coin, for which purpose it is well adapted by its beauty, lightness, sonority, and non-oxidizing quality. Laboratory weights have been made of the metal, and have remained standard for many years. Its solubility in the solutions of the alkalis is, as with copper and silver, such as to prevent its use for some purposes. It is very extensively used in making fine articles of luxury, and is proposed for use for philosophical and engineering apparatus, and for utensils to be used in the household.

Alloys of aluminium with other metals, with the exception of copper, are little known and are not in use. There are several manufactories of the metal producing a half ton, or less, annually. Its cost is about one-half that of silver; that of the bronze is about one-half that of the metal and several times that of copper-tin bronze.

Mercury (*Hydrargyrum;* Hg.), often called *quicksilver*, is used by the engineer for a number of important purposes. It is a dense fluid metal, having an atomic weight, 200, a specific gravity of 13.6, a specific heat of 0.032 to 0.0333 as it passes from the solid to the liquid state, a coefficient of expansion, according to Regnault, of from 0.00018 to 0.000197 as its temperature rises from the freezing point of water, 0°, to 350 Cent. (32° to 662° F.) Its latent heat of fusion is 2.82 metric units per unit of weight (5.08 British). It boils at about 350° C. (662° F.), forming a colorless, transparent, poisonous vapor, and evaporates at all temperatures. The density of its vapor, according to Dumas, is 6.976. It unites freely, at ordinary temperatures, with several other metals

forming "amalgams." Iron and platinum are not among these metals. Mercury is therefore preserved in iron bottles.

The Ores of Mercury are *cinnabar*, "vermilion," which is the sulphide, and *calomel*, the chloride; the former is the usual source of the mercury of commerce. The metal is sometimes found native, in small quantities; it is frequently alloyed slightly with silver. The ores of mercury are principally mined in California; but large quantities are produced also in Spain, Austria, and China.

Mercury, or "Quicksilver," is only produced in the United States, in California, where it is obtained from the red sulphide (cinnabar). The quantity produced is not far from 60,000 flasks of 76½ pounds each, per annum, and one-fourth as much more is imported. Its principal use is in the manufacture of vermilion (sulphide of mercury), and amalgamating mirrors.

Cinnabar is dark brown in color, earthy in texture, and very heavy, its specific gravity being 8.2; abrasion produces a red powder and a red streak on the mass. The ore is reduced by distillation and usually with considerable loss of vapor. The ore is broken up into pieces somewhat larger than an egg, and roasted in a deep furnace, of circular form, closed at the top and connected by flues with a set of condensing chambers in which the mercury is condensed by contact with iron plates, over which cooling streams of water are kept flowing. The charges weigh 700 or 800 pounds (318 to 363 kilogrammes), and are worked off in about three-quarters of an hour; the fuel used per charge is 25 or 30 pounds (11.3 or 13.6 kilogs.) of charcoal. In some cases, as in India, a reverberatory furnace is used in reducing the cinnabar, when the ore is lean. In still other cases, lean ores are distilled in small iron retorts, holding about 70 lbs. (32 kilogs.), with lime, and the vapors are condensed in stone bottles half filled with water, or, the retorts are larger and contain as much ore as the furnace above described. Condensation is effected in a "hydraulic main," kept cool by immersion in a trough of water.

Mercury, as distilled, usually contains bismuth, lead, and

zinc, and is often re-distilled in the iron bottles in which it is purchased from the smelter, or purified by washing with dilute nitric acid. A subsequent washing with water and drying with filter-paper and then warming it, leaves it in good condition. It is also purified by shaking with powdered sugar or with charcoal, the impurities being thus oxidized out by contact with air.

This metal is used in many kinds of philosophical apparatus, in the pressure gauges used for standardizing steam gauges, in the barometer, in "silvering" mirrors, and in a few alloys.

Mercury was the last metal discovered by the ancients, and is supposed to have been known four or five centuries before the Christian era. Red cinnabar, its sulphide, was, however, used as a cosmetic several hundred years earlier, and was imported into Greece and Italy, in enormous quantities, from the Spanish mines of Almaden. The Peruvians made similar use of it at the time of the discovery of their country by Pizarro.

Platinum (*Pt.*) is a metal possessing qualities of the highest value in the arts; but its considerable cost forbids its common use. It is so named from the Spanish *platina*, the diminutive of *plata*, silver, because of its white, silvery color. It is found in the mountainous portions of South America, Central America, Mexico and California, in the West Indies, and in the Ural Mountains, in the metallic state, but mingled with ore of iron, copper, and the rarer metals, and usually alloyed with a small quantity of iridium. Its atomic weight is 197.4.

The metal is purified by solution in a mixture of nitric and hydrochloric acids, precipitation by potassium chloride of the double chloride of potassium and platinum, re-solution by nitro-hydrochloric acid and reprecipitation by sal-ammoniac, sometimes, after repeated solution, as the double chloride of ammonium and platinum. The volatile element is driven off by heating, and the "spongy platinum" remaining is welded into a solid mass, after cleansing by trituration and washing.

Commercial Platinum always contains osmium and usually

silicium and iridium. Fusion in the oxy-hydrogen flame with proper fluxing removes these metals by oxidation and the promotion of slag. Deville and Debray fuse the ore with galena in a small reverberatory furnace, and, fluxing with glass and litharge, obtain an alloy of lead and platinum nearly free from other metals. This is expected to remove the lead, and the platinum so obtained is refined on the lime-covered hearth and thus obtained in a very pure state.

Various other ways are sometimes practised. The best method of compacting the metal is by fusion, which can be accomplished by the oxy-hydrogen flame in a little furnace made by forming a cavity between blocks of lime.

Platinum is nearly as ductile as gold and silver, and is only exceeded in malleability by those metals and copper. It is white like silver and has nearly as high a lustre. It is softer than silver and about as hard as copper; but it is rapidly hardened by the addition of traces of iridium or of rhodium. Its specific heat is 0.03243 at common temperatures, according to Regnault. The coefficient of expansion is 0.0000068 per degree, Cent., according to Calvert and Johnson, 0.0000085 per Bordaz, 0.000001 according to other authorities, varying according to purity and physical condition. Platinum can only be fused by the oxy-hydrogen flame or the voltaic arc. It is the heaviest of the metals used in the arts, having a specific gravity of 21.15 to 21.5. This metal is not oxidizable in the air or by any acid, although a mixture of nitric and muriatic acids will slowly dissolve it. At high temperatures, alkalis will produce corrosion by contact with it, as will potassium sulphate, and sulphur, phosphorus and arsenic. Chlorine attacks it slightly, iodine and bromine not at all.

Platinum is principally used in the manufacture of vessels required to resist heat or the action of acids, as crucibles, evaporating basins, stills or retorts used in the concentration of sulphuric acid, etc. Carbon and silica corrode it, and the metals, generally, freely alloy with it; its applications are thus somewhat restricted.

Platinum was discovered by the Spaniards, in the sixteenth

century, in the gold mines worked at the time, on the Isthmus of Darien; it only became valuable in the arts two centuries later, after Sickengen had, in 1772, found that it could be welded at a single white heat; it then came into demand, its hardness, strength, freedom from liability to oxidation, and especially its infusibility, giving it a value nearly equal to that of gold.

Magnesium, (*Mg.;* atomic weight, 24) is a silver white, lustrous metal, ductile and malleable, very light (s. g., 1.75), readily combustible, easily cut and worked, and resembling alumina in many respects. It melts and volatilizes like zinc, and at about the same temperature. In the form of powder or thin wire or ribbon, it takes fire like a shaving of wood and burns rapidly, with an intense bluish white light very rich in actinic rays.

It abounds in dolomitic limestone in the form of silicate and carbonate of magnesia, in *carnellite*, a double chloride of magnesium and potassium, from which it is reduced by sodium, using fluor spar as a flux, purifying it by distillation.

Magnesium has been manufactured by two establishments, the American Magnesium Company, Boston, United States, and the Magnesium Metal Company, Manchester, Great Britain. The English manufactory produced by far the most. The former furnished large quantities for the English army during the campaign in Abyssinia, the metal being employed extensively for signals.

Magnesium can readily be ignited at the flame of a candle. Combustion is frequently interrupted by the dropping off of the burning portion, so that it becomes necessary to feed the unburnt portion into the flame continually. The wire burns to the best advantage if inclined at an angle of about 45°.

An uninterrupted and very brilliant combustion is produced by lamps especially constructed for this purpose. Such a lamp* is made by the American Magnesium Company. The strips of magnesium are rolled up on cylinders in the upper part of the apparatus. These strips are unrolled by clockwork

* From designs patented by R. H. Thurston, 1865. New Marine Signal Light: Journal Franklin Institute, 1866.

in the lower part of the apparatus, and are carried between two small rollers, the uniform motion of which feeds them regularly into the lamp, where they are ignited. The ashes are cut off at intervals by means of eccentric cutters, and collect in the bottom of the apparatus. A small chimney is added, which is very important, as producing a draught of air directly through the flame. A portion of the products of combustion is thus carried away, and the flame becomes very intense, while it is less so without a draught. This lamp has been found very efficient, especially for marine signals. At trials made at sea, on two vessels stationed eight miles apart, the signals could be readily distinguished; it is said to be visible 28 miles.

Larkin has constructed and patented a lamp in which the magnesium is not employed as wire, or in strips, but as a powder. By this means the clock-work, or other mechanical device, has been dispensed with. The metallic powder is contained in a reservoir, which has a small opening in the bottom. The magnesium powder flows through this like the sand in the sand-clock. It is intimately mixed with a certain quantity of fine sand, in a manner diluted; first, in order to be able to make the opening sufficiently large; furthermore, to produce a continuous flow of the material. The mixture falls into a metallic tube, through which illuminating gas is led from the upper end. The mixture is ignited at the lower end. The flame is very brilliant, and the remaining sand falls into a vessel placed below, while the smoke passes away through a chimney. A lamp of this character was adopted in several forms of signal apparatus devised for the Army and the Navy Signal Corps, by the Author, in the years 1866–70.

Arsenic (*As.*; atomic weight, 75) is found native, but is usually obtained from the sulphite or from the alloy with iron known as arsenical iron. It is also found alloyed with other metals. It is reduced from arsenical pyrites, or from arsenical iron, by roasting in retorts, the arsenic passing off by sublimation and condensing outside as in the zinc manufacture. The arsenic of commerce is made principally from German

and Spanish ores. The oxide is easily reduced by heating with carbon.

This metal is a gray, lustrous solid, of steely fracture and color, having a density of 5.6 to 5.95, crystallizing in rhombohedra, volatilizing at a red heat, with a garlic-like odor, and oxidizing easily at a high temperature, but not readily at a low temperature. It has no value in the arts of construction and engineering except in alloys.

Iridium (*Ir.;* atomic weight, 197) is the heaviest of useful metals. It was discovered in the year 1803 by Tennant, who analyzed the metallic residue which remains when platinum ores are dissolved. Tennant proved that the platinum residues contained two new metals, to one of which he gave the name of iridium, on account of the varying color of its salts, and to the other the name osmium, because of the peculiar odor which its volatile oxide possesses. Iridium is found in the platinum ores in considerable quantity in the form of the alloys of platiniridium and osmiridium. The first of these occurs in grains and small cubes with rounded edges; the second, usually, in flat, irregular grains, and sometimes in hexagonal prisms. Iridium, in the cold state, resists the action of acids and alkalies. It parts with its oxygen at a high heat, and, although it possesses a number of valuable qualities, has been used, until recently, only for the points of gold pens. Its limited use was caused by the difficulty of obtaining it in metallic form. It is found in Russia, Brazil, California and several other countries, and is usually accompanied by gold or platinum. Since its discovery, numerous chemists and metallurgists have unsuccessfully endeavored to reduce the ore and obtain iridium in the metallic form. Chemists have succeeded in producing some small pieces of iridium the size of a pea by means of the oxyhydrogen blowpipe flame, the metal obtained, however, being porous and valueless. In 1855, George W. Sheppard, of Cincinnati, succeeded in producing a similar result with the aid of a powerful galvanic battery. Later, John Holland, of that city, began experimenting in the same direction, and after several years of trial succeeded in reducing the iridium ore to a solid

metal in common furnaces. He used phosphorus as a flux, by means of which, it was said, the metal could be made to fuse as easily as cast iron.

This new method of fusing iridosmine was discovered in 1881; it consists in heating the ore to whiteness and adding phosphorus. The mass becomes at once fused, and the phosphide thus obtained is reduced by heating with lime. The metal is exceedingly hard, has a brilliant metallic lustre and is not attacked by acids; when pure, its density is 18.7.*

The ore used as above, and the metal, have been examined by Clarke and Joslin.† The ore has a specific gravity of 19.182, the metal 13.77. The composition of the latter was

Iridium	80.82
Osmium	6.95
Phosphorus	7.09
Ruthenium, Rhodium	7.20
	102.06

showing the fused metal to be a phosphide, of the formula, Ir_2P.

Phosphorus was found to re-act similarly with platinum.

Manganese (*Mn.*; atomic weight, 55) is usually found as a peroxide, although occurring in many other compounds. Its oxide is reduced by carbon at a white heat, usually by heating the peroxide in powder with oil. The metal is also obtained by heating the chloride or fluoride with sodium. It is gray in color, resembling light gray cast iron, usually weak and brittle, heavy (s. g., 7 to 8) and slightly magnetic.

It has a strong affinity for oxygen, and it is this which makes it valuable in the arts. In one of its forms it is quite different, however. As reduced from the chloride by sodium it is hard and does not easily oxidize.

Manganese is always used as an alloy. Its most usual form is seen in "*spiegeleisen*," an alloy with iron used in the

* Proc. Ohio Mechanics' Institute, 1882.

† *Am. Chemical Journal*, vol. v. No. 4, 1883.

Bessemer and other processes of steel-making, which is made by direct reduction from manganiferous ores by the ordinary small charcoal blast-furnace. It is cast either into pigs or into flat plates. When very rich in manganese and comparitively low in carbon, it is called "*ferro* manganese." Spiegeleisen contains from 3 or 4 to 8 or 10 per cent. manganese, while ferro-manganese contains 10 to 30 per cent.

The Rare Metals are of no value to the engineer in his everyday work; they are enormously costly, and possess, as a rule, none of the qualities which are essential to their use in construction. They are here only referred to, to complete the list.

Gold and silver are too well known to demand description. They are both dense, but soft, metals, difficult of oxidation, little subject to corrosion, and therefore sometimes very useful in plating other metals not readily attacked by acids, alloying with copper and some other metals readily, and forming compounds which, like these metals themselves, are of little or no value to the engineer.

Cadmium is a white, malleable and ductile metal resembling tin. Its sulphide, known as cadmium yellow, is bright in color and has qualities of great value to artists. The metal is of little use.

Calcium is yellow, ductile and malleable, and softer than gold. At a red heat it burns with a dazzling white light.

Erbium is very rare; it resembles aluminium in its properties and compounds.

Glucinum is white, malleable and moderately fusible, resembling aluminium.

Lithium is a metal resembling silver in color. It admits of being drawn into wire, but has little tenacity. It is remarkable for its lightness and the readiness with which it combines with oxygen.

Molybdenum is a silvery white, brittle and infusible metal. It never occurs native, and neither it nor its compounds are of practical use.

Osmium is remarkable for its high specific gravity and infusibility.

Palladium resembles platinum. An alloy of 20 per cent. with 80 per cent. gold is perfectly white, very hard and does not tarnish by exposure.

Rhodium is white, very hard and infusible. Its specific gravity is about 11.

Ruthenium resembles iridium. It is rare and of little value.

Strontium is yellowish, ductile and malleable; it burns in the air with a crimson flame.

Thallium is very soft and malleable.

Thorium is an extremely rare metal, remarkable for taking fire below red heat, and burning with great brilliancy. Neither the metal nor its compounds are of practical use; its oxide has the high specific gravity of 9 4.

Titanium is a rare metal, usually obtained in crystalline form, and also as a heavy iron-gray powder. The crystals are copper-colored and of extreme hardness.

Tungsten is a hard, iron-gray metal, very difficult of fusion. An alloy of ten per cent. of this metal and 90 per cent. of steel is of extreme hardness. Both the metal and its compounds have proved of value alloyed in steel and bronze.

Uranium is very heavy and hard, but moderately malleable, resembling nickel and iron; it is unaltered at ordinary temperatures by air or water.

Rubidium and caesium so closely resemble platinum that no ordinary test will distinguish them.

Indium is very soft, malleable and fusible; it marks paper like lead.

Barium, cerium, columbium (or niobium), didymium, lanthanium, tantalum, terbium, yttrium, and zirconium, are all rare metals and not very well known.

The Commercial Metals are never chemically pure. Lake Superior copper and the best grades of tin are practically so, but all other metals have such a variety of quality and composition, as sold in our markets, that the purchaser and consumer can only rely upon careful analyses to determine their value for any proposed use. This precaution is

especially advisable when the engineer selects metals or alloys for use in construction.

Thus copper has been found to contain as much as 30 per cent. lead and 8 or 9 per cent. of nickel, iron, arsenic, and other metals; lead often contains several per cent. of antimony, arsenic, zinc, and other elements; iron may contain besides the sulphur and phosphorus which frequently seriously injure it, a considerable amount of manganese, chrome, nickel and cobalt, and even copper; platinum often contains appreciable quantities of the other rare metals, as paladium, rhodium, usually iridium and osmium, and sometimes iron and copper; zinc is very frequently rendered useless for the engineer's purposes by the presence of lead.

The Prices of Metals are so constantly varying that no list can be given of great accuracy. The cost of reduction, the relations of supply and demand, and the accidental fluctuations of the market combine to determine the exact figures. The following table, calculated by Bolton,* may be taken as representing approximate values for good times.

PRICES OF METALS.

METAL.	STATE.	VALUE IN GOLD PER LB. AVOIRDUPOISE.	PRICE IN GOLD PER GRAMME.	AUTHORITY.
Vanadium	Cryst. fused	$4,792.40	$10.80	S.
Rubidium	Wire	3,261.60	7.20	S.
Calcium	Electrolytic	2,446.20	5.40	S.
Tantalum	Pure	2,446.20	5.40	S.
Cerium	Fused globule	2,446.20	5.40	S.
Lithium	Globules	2,228.76	4.92	S.
Lithium	Wire	2,935.44	6.48	S.
Erbium	Fused.	1,671.57	3.96	S.
Didymium	"	1,630.08	3.60	S.
Strontium	Electrolytic	1,576.44	3.48	S.
Indium	Pure	1,522.08	3.36	T.
Ruthenium	.....	1,304.64	2.88	T.
Columbium	Fused	1,250.28	2.76	S.
Rhodium	.....	1,032.84	2.28	T.
Barium	Electrolytic	924.12	2.04	S.
Thallium	.....	738.39	1.63	T.
Osmium	.....	652.32	1.44	T.
Palladium	.....	498.30	1.10	T.

* *Engineering and Mining Journal*, Aug. 21, 1875.

PRICES OF METALS.—*Continued.*

METAL.	STATE.	VALUE IN GOLD PER LB. AVOIRDUPOISE.	PRICE IN GOLD PER GRAMME.	AUTHORITY.
Iridium	.....	$466.59	$1.03	T.
Uranium	.....	434.88	.96	T.
Gold	.....	299.72	.....	....
Titanium	Fused	239.80	.52	....
Tellurium	"	196.20	.43	....
Chromium	"	196.20	.43	....
Platinum	"	122.31	.27	....
Manganese	"	108.72	.24	T.
Molybdenum	.....	54.34	.12	T.
Magnesium	Wire and tape	45.30	.10	T.
Potassium	Globules	22.65	.05	T.
Silver	.....	18.60	.....	....
Aluminium*	Bar	16.30	.036	S.
Cobalt	Cubes	12.68	.028	S.
Nickel	"	3.80	.008	T.
Cadmium	.....	3.26	.007	T.
Sodium	.....	3.26	.007	T.
Bismuth	Crude	1.95	.0043	S.
Mercury	.....	1.00	.....	....
Antimony	.....	.36	.....	T.
Tin	.....	.25	.....	....
Copper	.....	.22	.....	....
Arsenic	.....	.15	.....	....
Zinc	.....	.10	.....	....
Lead	.....	.06	.....	....
Iron	.....	.01½	.....	....

The prices of many may be considered also as "fancy prices," and a whole pound of some of the metals named could hardly be obtained at even these figures. In compiling the table, the prices of the rarer metals are obtained from Trommsdorff's and Schuchardt's price lists; the avoirdupois pound is taken as equal to 453 grammes, and the mark as equal to 24 cents gold.

It is evident that the prices of the metals bear no relation to the rarity of the bodies whence they may be derived; for calcium, the third in the list, is one of the most abundant elements. Even indium, the most recently discovered element, stands tenth in the list, below strontium.

* Since 1884 reduced by Cowles' process to $5 per pound.

CHAPTER VIII.

THE BRONZES AND OTHER COPPER-TIN ALLOYS.

The Alloys of Copper, with smaller quantities of the more common metals, are the most valuable and the most common, and the most extensively used of all compounds or mixtures known to the engineer and the metallurgist. Those which are produced by the union of copper and tin are generally classed as the "Bronzes." When copper is alloyed with zinc, the composition is known as "Brass." These terms are not exclusively so applied, however, and the term brass is not infrequently used to cover the whole series of alloys composed, wholly or in part, of alloys of copper and tin, copper and zinc, or combinations of brass and of bronze with each other or with less quantities of other metals. *Bronzes* are here supposed to contain principally *copper and tin.* These alloys are produced by the union, either chemically or by solution, when molten, of two or more metals. Nearly all metals can unite with nearly all other metals in this manner, and the number of possible combinations is infinite; nevertheless, but few alloys are found to be very generally used in the arts. It is considered probable that the metals may combine chemically in definite proportions, but the compounds thus produced usually dissolve in all proportions in either of the constituents, and it is rarely possible to separate the chemically united portions. In some cases the affinity is very slight, as between lead and zinc, either of which will take up but about one and a half per cent. of the other. The alloys are usually the more stable as their constituents are the more dissimilar, and, when this difference is chemically great, the compound becomes brittle. Occasionally, an alloy is formed which gives evidence of the occurrence of chemical union, by the production of heat; this is seen in some copper-zinc alloys.

Copper alloys are formed with nearly all metals with great facility, and with no other precaution than that of either preventing access of oxygen to the molten mass, or of thoroughly fluxing the alloy, to take up such as may have combined with it. Many of these alloys were once considered chemical compounds; but the view which seems most generally accepted, at the present time, is that they are almost invariably either mere mixtures, or that a species of solution of the one metal in the other takes place.

The most minute trace of foreign element often produces an observable, or even an important, alteration of the properties of copper. This is especially true of its conductivity for electricity, which is reduced greatly by an exceedingly minute proportion of iron or lead.

History.—The alloys of these metals were used extensively by the ancients for coins, weapons, tools and ornaments, and the composition of their bronzes, as shown by recent analyses, indicates that they were as skilful in brass-founding as the modern workman.

Thus, Phillips gives the following as the results of his own examinations and as showing the proportions of the constituents employed in the manufacture of brass, at times both preceding and closely following the Christian era:

	DATE.	COPPER.	ZINC.	TIN.	LEAD.	IRON.
Large brass of the Cassia family..	B C. 20	82.26	17.31	....	....	.35
" " Nero " ..	A.D. 60	81.07	17.81	1.05	....	....
" " Titus " ..	" 79	83.04	15.84	....	....	.50
" " Hadrian " ..	" 120	85.67	10.85	1.14	1.73	.74
" " Faustina " ..	" 165	79.14	6.27	4.97	9.18	.23

Thus, copper and zinc were the essential constituents of the alloys examined; but then lead was sometimes present in considerable quantities, together with tin and iron. Although zinc occurs in such considerable quantities in these alloys, it

was not known in the metallic state until about the thirteenth century, when it was described by Albert of Bollstadt.

Many analyses of ancient articles of bronze have been made, and our knowledge of this very old alloy is considerably greater than that of the alloys of zinc. The proportion of the constituent metals was varied according to the purpose to which the alloy was to be applied, as will be seen from the following analyses, the hardness being modified according to the proportion of tin present. The alloys containing the largest amount of tin were used for mirrors, while those of medium hardness were used for sword-blades and other cutting instruments:

	COPPER.	TIN.	LEAD.	IRON.	COBALT.	ANALYST.
1. Chisel, from ancient Egyptian quarry.	94.00	5.90	....	.10	....	Wilkenson.
2. Bowl, from Nimroud.	89.57	10.43	....	....	....	Dr. Percy.
3. Bronze overlaying iron	88.37	11.33	....	....	....	"
4. Sword-blade, Chertsey, Thames	89.69	9.58	....	.33	.. .	J. A. Phillips.
5. Axe-head	88.c5	11.12	.78	....	....	Prof. Wilson.
6. Celt	81.19	18 31	.78	....	....	"
7. Roman As, B.C. 500	69.69	7.16	21.82	.47	.57	J. A. Phillips.
8. Julius Cæsar	79.13	8.00	12.81	....	....	"

The third specimen was analyzed by Dr. Percy, who describes it as a small casting in the shape of the foreleg of a bull, forming the foot of a stand, consisting of a ring of iron supported upon three bronze feet. A longitudinal section disclosed a central core of *iron*, around which the bronze had been cast.

Some writers, to account for the immense masses of hard stone wrought by the Egyptians and ancient Americans, suppose that they possessed means of hardening bronze to a degree equal to that of our steel; this requires confirmation, since no remains of bronze of such a hard variety have ever been discovered.

The bronze weapons discovered by Dr. Schliemann among the ruins excavated by him at or near the site of ancient Troy* were often of nearly the composition of modern gun-bronze; they contained copper 90 to 96, tin 8.6 to 4. The date,

* "Troy and its Remains;" London and New York, 1875; p. 361.

archæologically, is at the beginning of the "bronze age," and immediately at the close of the "stone age." Sir John Lubbock finds the bronze implements and ornaments of the bronze age as remarkable for their beauty and variety as for their utility.* They consisted of axes, arrow-heads, knives, swords, lances, sickles, ear-rings, bracelets, rings, etc., etc.

The bronze used by the prehistoric nations contained no lead; that of the Romans and post-Romans was rarely of pure copper and tin, but were usually more or less alloyed with lead. Silver, zinc, and lead was not known in the bronze age. The prehistoric bronzes were cast, sometimes in metal or in stone, and sometimes in sand, moulds. A more common method was by wax models, or "patterns," which were used to make the desired cavity in an earthen or sand mould, the wax being melted out afterward.

According to Charnay,† the Aztecs discovered a means of tempering copper, and of giving to it a considerable degree of hardness, by alloying it with tin. Copper hatchets were known among them; since Bernal Diaz states in the narrative of his first expedition to Tobasco, that the Spaniards bartered glass-ware for a quantity of hatchets of copper, which at first they supposed to be gold. Copper abounded in Venezuela, and we still find there in great numbers trinkets of copper mixed with gold, or of pure copper, representing crocodiles, lizards, frogs and the like.

In cutting down trees, they employed copper axes like our own, except that, instead of having a socket for the haft, the latter was split, and the head of the axe secured in the cleft.

The hatchet described seems to have been a piece of native copper wrought and fashioned with a stone hammer. The Aztecs made good bronze chisels, as described by Señor Mendoza, director of the National Museum of Mexico. He describes certain specimens of bronze chisels belonging to the collection in that museum. When freed from oxide the bronze presents the following characteristics: In color it resembles gold; its density is 8.875; it is malle-

* "Prehistoric Times;" London and New York, 1872.

† *N. A. Review*, 1875; Ruins of Central America.

able, but unlike pure copper, is hard, and breaks under strong tension or torsion; the fracture presents a fine granulation like that of steel; in hardness, it is inferior to iron, but it is sufficiently hard to serve the purpose for which it was intended. One of these chisels was found to consist of copper 97–87 per cent., tin 2–13 per cent., with traces of gold and zinc.

The bronzes were used by the ancients in the manufacture of weapons and of tools. The use of phosphorus increases the purity and adds strength and hardness to these alloys, and the remarkable hardness of ancient bronze weapons is found by Dr. Reyer to be due, in part at least, to the presence of phosphorus, probably introduced with the flux used in melting. The proportion of tin varied up to 20 per cent.

The Alloys of Copper and Tin have many uses in the arts. The two metals will unite to form a homogeneous alloy in a wide range of proportions. As tin is added to pure copper, the color of the alloy gradually changes, becoming decidedly yellow at 10 per cent. tin and turning to gray as the proportion approaches 30 per cent. In the researches conducted by the Author, it was found that good alloys may contain as much as 20 per cent. tin. When the color changes from golden yellow to gray and white, the strength as suddenly diminishes; and alloys containing 25 per cent. tin are valueless to the engineer; nevertheless, this alloy and those containing up to 30 per cent. show compressive resistances increasing to a maximum. The tensile and compressive resistances have no known relation; the torsional resistance is more closely related to tenacity.

A small loss of each constituent occurs in melting, the loss often being highest with the metal present in the lowest proportion; this loss rarely exceeds one per cent., except when the fusion has taken place slowly with exposure to the air, when considerable copper-oxide is liable to form. The specific gravities of these alloys do not differ much from 8.95.

Under 17.5 per cent. tin, the elastic limit lies between 50 and 60 per cent. of the ultimate strength; beyond this limit the proportion rises, and at 25 per cent. tin the elastic limit

and breaking point coincide. Passing 40 per cent. tin, this change is reversed and the elastic limit, although indefinite, is lowered until pure tin is reached and a minimum at about 30 per cent.

The modulus of elasticity of all the bronzes lies between ten and twelve millions.

Riche states that tempering produces on steel, forged or annealed, an inverse effect to that which it produces on bronzes rich in tin; it diminishes its density instead of in creasing it, from which it may be seen that tempering diminishes the density of annealed steel and makes it hard, while tempering increases the density of annealed bronze and makes it soft.

There is always an increase in density, whether the bronzes rich in tin be tempered, or slowly cooled, after compression.

These experiments confirm most clearly the fact affirmed by D'Arcet, that tempering softens the bronzes, rich in tin, for we can flatten in the press the tempered bronzes, while it is impossible to do this with steel.

It is evident from his experiments that tempering augments considerably the density of bronze rich in tin, and that annealing evidently diminishes the density of tempered bronze. Still the effect of slow cooling by no means destroys the effect of tempering, for the density continues to increase till it becomes remarkable.

While all mechanical action increases the density of the annealed bronze, it very slightly, but still sensibly, diminishes the density of annealed steel, and, on the whole, tempering and shock increase the density of annealed bronze, while they diminish the density of annealed steel.

But the variations are very decided for bronze and very slight for steel.

Bronze of 96 and 97 parts copper may be employed to great advantage, and with no serious inconvenience, in the manufacture of medals. Its hardness, much less than that of the alloy of M. de Puymaurin, does not much exceed that of copper; it possesses a certain sonority and casts well, rolls evenly, and its color is more artistic than that of copper.

The action of the press and of heat modify its density but little.

Properties.—Copper and tin alloy in all proportions, and the most useful compounds known to the engineer are the "bronzes," as these alloys are called. They include gun-metal, bell-metal and speculum alloys. The following is Mallet's list of these alloys and table of their properties.*

PROPERTIES OF COPPER-TIN ALLOYS.

At. wt.: Cu. = 31.6; Sn = 58.9.

AT. COMP.	COPPER.	S. G.	COLOR.	FRACT.	TENACITY.	MALL.	HARD.	FUS.
Cu Sn	per ct.				Tons per sq. in.			
1 : 0	100.	8.607	red-yellow	.....	24.6	1	10	16
a 10 : 1	84.27	8.561	"	fine grain	16.1	2	8	15
b 9 : 1	82.81	8.462	yellow-red	"	15.2	3	5	14
c 8 : 1	81.10	8.459	"	"	17.7	4	4	13
d 7 : 1	78.97	8.723	pale red	vitreous	13.6	5	3	12
e 6 : 1	76.29	8.750	"	"	9.7	brittle	2	11
f 5 : 1	72.80	8.575	ash gray	conchoid.	4.9	"	1	10
g 4 : 1	68.21	8.400	dark gray	"	0.7	friable	6	9
h 3 : 1	61.69	8.539	white gray	"	0.5	"	7	8
i 2 : 1	51.75	8.416	white	lam. grain	1.7	brittle	9	7
j 1 : 1	34.92	8.056	"	vitreous	1.4	"	11	6
k 1 : 2	22.15	7.387	"	lam. grain	3.9	"	12	5
l 1 : 3	15.17	7.447	"	"	3.1	8 tough	13	4
m 1 : 4	11.82	7.472	"	"	3.1	6 "	14	3
n 1 : 5	9 63	7.442	"	earthy	2.5	7	15	2
o 0 : 1	0.	7.291	"	.....	2.7	.....	16	1

a, *b*, *c* are gun-metals; *d*, hard brass for pins; *e*, *f*, *g*, *h*, *i*, bell-metal; *j*, *k*, for small bells; *l*, *m*, *n*, *o*, are speculum alloys.

The addition of a small quantity of tin to copper causes it to become brittle under the hammer, according to Karsten, and the ductility is restored only by heating to a red heat and suddenly cooling. Mushet finds that the alloy, copper 97, tin 2, makes good sheathing, as it is not readily dissolved in hydrochloric acid. The best gun-metal is from copper 90, tin 10, to copper 91, tin 9; if richer in copper, it is especially liable to liquation, which action is detrimental to all these alloys. Bell-metal, copper 80, tin 20, to copper 84, tin 16, is sonorous and makes good castings, but is hard, difficult to

* *Dingler's Journal*, lxxxv., p. 378; Watts's Dict. ii., p. 43.

work and quite brittle. Suddenly cooling it from a high temperature reduces its brittleness, while slow cooling restores its hardness and brittleness. It is malleable at low red heat and can be forged by careful management.

Speculum-metal, copper 75, tin 25, is harder, whiter, more brittle and more troublesome to work than bell-metal.

Old flexible bronzes contain about ¾ ounce of tin to the pound of copper, or copper 95, tin 5, as stated by Ure. Ancient tools and weapons, as shown elsewhere, contain from 8 to 15 per cent. tin; medals from 8 to 12 per cent., with often 2 per cent. zinc to give a better color. Mirrors contained from 20 to 30 per cent. tin. The metals mix in all proportions, and the alloys are, to a certain extent, independent of their chemical proportionality. The occurrence of hard, brittle, elastic alloys between the extremes of a series having soft tin and ductile copper at either end, both of which metals are inelastic, is probably a proof that these alloys are sometimes chemical compounds. They are probably, usually, compounds in which are dissolved an excess of one or the others of the components.

The Principal Bronzes are those used in coinage, in ordnance, in statuary, in bells, and musical instruments, and in mirrors and the specula of telescopes. These alloys oxidize less rapidly than copper, are all harder, and often stronger and denser.

Coin bronze, as made by the Greeks and Romans, contained from copper 96, tin 4, to copper 98, tin 2, and Chaudet has shown that the first of these alloys can be used for fine work, obtaining medals of this composition of very perfect polish while sufficiently hard to wear well. Puymaurin succeeded well with alloys of copper 93.5, tin 6.5, to copper 90, tin 10; and Dumas found the range of good alloys for this purpose quite large, varying from 96 copper, 4 tin, to 86 copper, 14 tin, but the best faliing near the middle of this range.

Gun bronze has various compositions in different countries. The most common proportion would seem to be copper 90, tin 10, or copper 89, tin 11. Well made, it is solid, yellowish, denser than the mean of its constituents, and much harder,

stronger, and more fusible than commercial copper; it is somewhat malleable when hot, much less so when cold.

It is subject to some liquation, and should therefore be quickly chilled in the mould; it loses some tin when permitted to stand at a temperature of 400° to 500° Fahr. (200° to 260° C.). This liquation gives rise to light-colored spots throughout the metal. This bronze does not readily oxidize at ordinary temperatures, but is quickly attacked when hot; it usually becomes greenish when exposed to the weather, by the formation of the hydrated carbonate; thus "patina" is observed on all unpolished old bronze guns or old statues.

Statuary bronze is usually of nearly the same composition as gun-bronze. It should be rapidly melted, poured at high temperature, and quickly cooled to prevent liquation.

Bell-metal is richer in tin than the preceding, and varies in composition somewhat with the size of bell. The proportion, 77 copper, 23 tin, is said to be a good one for large bells; it shrinks 0.015 in the mould while solidifying. The range of good practice is found to be from 18 to 30 per cent. tin, 82 to 70 per cent. copper; the largest proportions of tin are used for the smallest bells, and an excess is added to meet the liability to oxidation and liquation; copper 78–82, tin 22–18, is a very usual composition. When made of scrap metal, as is not uncommon, serious loss of quality is liable to occur by the introduction of lead and other metals deficient in sonorousness. When properly made, this alloy is dense and homogeneous, fine-grained, malleable if quickly cooled in the mould, rather more fusible than gun-bronze, but otherwise quite similar; excelling, however, in hardness, elasticity and sonority.

These bronzes become quite malleable when tempered by sudden cooling, and this treatment is resorted to when they are to be subjected to prolonged working or to a succession of processes. Chinese gongs are made of copper 78 to 80, tin 22 to 20, and are beaten into shape with the hammer, the metal being softened at frequent intervals by heating to a low red heat and plunging into cold water. The tone desired is obtained by hammering the instrument until the proper degree of hardness is obtained. Tempering not

only increases the ductility and malleability of these alloys, but also, it is claimed, their strength, while decreasing their hardness and density, when they are made into thin sheets; thick plates are less affected; annealing by slow cooling pro duces an opposite effect.

Speculum-metal contains, often, as much as 33 per cent. tin; it is steely, almost silvery white, extremely hard and brittle, and capable of taking a very perfect polish. The most suitable proportion of tin varies slightly with the character of the copper, some kinds requiring more and some less to give the degree of whiteness and the perfection of polish required. An excess of tin injures the color and reduces the lustre of the mirror.

The finest speculum metal is perfectly white, without a shade of yellow, sound, uniform, and tough enough to bear the grinding and polishing without danger of disintegration. The specula made by Mudge were twice fused, and contained from 32 parts copper and 16 tin to 32 copper and 14.5 tin. A little tin is lost in fusion. According to David Ross, the best proportions are: copper, 126.4; tin, 58.9, *i.e.*, atomic proportions. He adds the molten tin to the fused copper at the lowest safe temperature, stirring carefully, and securing a uniform alloy by remelting, as is often done in making ordnance bronze.

Bronze for bearings and pieces subject to severe friction, as in machinery, is made of many proportions. Gun-bronze is one of the best; the Author has known of one case in which the bronze was made of ingot copper 90, ingot tin 10, and used in the main crank-shaft journal of a steam vessel for ten years without appreciable wear, although the area was not unusually large for the load and the velocity of rubbing was high, as is usual in screw engines. The proportions given in several cases will be found elsewhere; they vary in practice from 88 to 96 per cent. copper, as more or less hardness is required. Bronze for steam engine packing rings is sometimes made of 92 to 94 copper, 7 to 9 parts tin, 1 part zinc.

The fracture is of a uniform yellow color, with an even grain. The specific gravity of bronze is about 8.7, being greater than the mean of the specific gravities of copper and tin.

Copper proposed to be used in ordnance bronze should be condemned for the manufacture of guns, if it contains sulphur in an appreciable quantity; more than one-thousandth of arsenic and antimony united; more than about three-thousandths of lead, iron, or oxygen; if it contain more than about five-thousandths of foreign substances altogether; or if, near these limits, it give bad results when subjected to the mechanical tests of hammering, rolling, and wire-drawing.

It is also stated that tin offered should be rejected if, when run into elongated drops, it have not a smooth and reflecting surface, without any considerable sign of rough spots; if, when analyzed, it contain more than about one-thousandth of arsenic and antimony united; more than about three-thousandths of lead or iron; or more than four-thousandths of foreign substances.

All *bronze* ought to be rejected which contains sulphur in an appreciable amount; which contains more than about one-thousandth of arsenic and antimony united; more than about three-thousandths of lead, iron, or zinc; or, in all, more than about five-thousandths of foreign substances.

Notice should be taken of the appearance of the fracture of specimens; it sometimes gives indications sufficient to authorize the rejection of certain bronzes full of sulphur or oxides.

Gun-metal, when broken, should present a fine, close-grained fracture, of a uniform, beautiful golden color; it should be ductile, although finely granular and possibly crystalline. Bronze guns often exhibit, when burst, a decidedly crystalline surface, the axes of the crystals lying radially to the bore.

According to the practice of the Navy Department, the bronze used for rifled howitzers is composed of Lake Superior copper 9 parts, tin 1 part. This is used when the casting is made in a sand mould. When a chill mould is used, which is the method now adopted for such castings, the proportion is changed to 10 to 1.

The copper is melted in a reverberatory furnace, and three hours after the fires are started, when the copper is in perfect fusion, the tin is stirred in; half-an-hour after, the bronze is run off into the moulds. The casting cools naturally, and is taken out of the mould about twenty-four hours after the metal is run in. The chill mould is warmed sufficiently to drive out the moisture.

Phosphor-Bronze and Manganese Bronzes are alloys which are now so well known and have become so important in the arts as to demand special notice.

Phosphor bronze has been known many years. It consists simply of any alloy of bronze or brass or any ternary alloy of copper, tin and zinc which has been given exceptional purity and excellence by skilful fluxing with phosphorus. It is also supposed that the presence of phosphorus is useful in giving the tin a crystalline character which enables it to alloy itself more completely and strongly with the copper. Phosphor-bronze will bear remelting with less injury than will common bronze. The phosphor bronzes greatly excel the unphosphuretted alloy in every valuable commercial quality, and they are very extensively used for every purpose for which such alloys are fitted.

The following are Kirkaldy's figures for tenacity and ductility of phosphor-bronze wire of No. 16 Birmingham gauge:

PHOSPHOR-BRONZE WIRE, NO. 16, B. W. G.

MATERIALS.	LOAD AT FRACTURE.				Elongation, Length 5 in.	No. twists before breaking.	
	Unannealed.		Annealed.				
	Per sq. mm.	Per sq. in.	Per sq. mm.	Per sq. in.	Per cent.	Unannealed.	Annealed.
Phosphor-bronze of several proportions,	72.3 kil.	46 T.	34.7 kil.	22 T.	37.5	6.7	80
	85.1	54	33.6	21.3	34.1	22.3	52
	85.2	54.1	37.5	23.8	42.4	13.0	124
	97.7	62.1	42.8	27.2	44.9	17.3	53
	112.2	71.2	41.7	26.5	46.6	13.3	66
	106.3	67.6	45.4	28.9	42.8	15.0	60

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility. (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet)	Order of fusibility (Mallet).	Conductivity for heat, silver = 100	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
1	.....	100	0	.....	.....	{ 8.791 a / 8.874 b }	Copper red	Fibrous	27,800	....	30.8	.....	....	....	....	....	U. S. B.	{ a Specific gravity of bar. b Specific gravity of turnings from ingot.
2	.....	100.00	0.00	.....	.....	8.667	Tile red	Earthy	55,104	1	.....	10	2	16	....	.....	M.	
3	.....	100.00	0.00	.....	.....	8.921	.....	.....	.....	....	.....	.....	....	....	..	93.16	Ma.	
4	.....	100.00	0.00	.. ...	.....	.....	.....	.....	.....	....	.....	301	....	....	81.2	.....	C. J.	
5	.. ....	100.00	0.00	.....	.....	8.794	.....	.....	.....	....	.....	.....	....	....	....	.....	Cr.	
6	.....	100.00	0.00	.....	.....	8.921	.....	.....	.....	....	.....	.....	...	....	....	.....	Mar.	Cast copper.
7	.....	100.00	0.00	.....	.....	8.952	.....	.....	.....	....	.....	.....	....	....	....	.....	Mar.	Sheet copper.
8	.....	100.00	0.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	73.6	79.3	We.	
9	.....	100.00	0.00	.....	.....	8.672	.....	.....	24,252	.. .	.....	.....	....	....	....	.....	Na.	Mean of 9 samples.
10	.....	98.59	1.41	.....	.....	.....	.....	.....	.....	....	.....	... ..	....	....	....	62.46	Ma.	
11	$SnCu_{86}$.	98.10	1.90	97.89	1.90	8.564	Red	Vesicular	.....	....	100.1	.....	....	....	....	.....	U. S. B.	Defective bar.
12	.....	98.04	1.96	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	....	.....	B.	Can be forged like copper.
13	.....	98.00	2.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	La.	Ramrods for guns.
14	.....	97.50	2.50	.....	.....	8.511	Red	Vesicular	.....	....	.....	.....	....	....	....	.....	U. S. B.	Defective bar.
15	.....	96.97	3.03	.....	.....	.....	.....	.....	.....	....	.....	.....	...	....	....	.....	W.	Resists action of hydrochloric acid.
16	$SnCu_{48}$.	96.27	3.73	96.06	3.76	8.649	Reddish yel.	Vesicular	32,000	....	70.3	.....	....	....	....	.....	U. S. B.	
17	.....	96.00	4.00	.....	.....	8.947	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	Annealed and compressed.
18	.....	95.00	5.00	.....	.....	.....	Golden yel.	.....	.....	....	.....	.....	....	....	....	.....	W.	Hard malleable.
19	.....	94.10	5.90	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	....	.....	B.	Pieces of machines.
20	.....	94.00	6.00	.....	.....	8.939	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	Specific gravity after repeated tempering.
21	.....	93.98	6.02	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	....	19.68	Ma.	

22	$SnCu_{22}$	93.17	6.83	.....	.....	8.820	.....	.....	28,540	....	21.9	602.8	....	...	....	.....	C. J.	
23	$SnCu_{21}$	92.80	7.20	.....	.....	8.694	Reddish yel.	Vesicular	28,540	....	21.9	.....	....	...	....	.....	U. S. B.	
24	.....	92.50	7.50	.....	.....	8.684	" "	"	27,900	....	43.2	.....	....	...	....	.....	U. S. B.	
25	.....	92.00	8.00	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	Bronze for medals.
26	.....	91.75	8.25	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	W.	Shows liquation.
27	.....	91.74	8.26	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	English Ordnance.
28	.....	91.70	8.30	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	Ordnance-metal.
29	.....	91.66	8.33	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	8-pounder guns.
30	$SnCu_{20}$	91.49	8.51	.....	.....	8.793	.....	.....	.....	...	.....	639.58	....	...	....	.....	C. J.	
31	.....	91.30	8.70	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	Toothed wheels.
32	.....	90.91	9.09	.....	.....	.....	.....	.....	32,093	....	.....	.....	....	...	....	.....	Mus.	Prussian ordnance.
33	.....	90.90	9.10	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	Ordnance-metal.
34	.....	90.73	9.27	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	French ordnance.
35	.....	90.10	9.90	.....	.....	.....	.....	.....	.....	...	.....	.....	....	...	....	.....	B.	
36	.....	90.00	10.00	90.27	9.58	8.669	Grayish yel.	Earthy	26,860	....	18.0	.....	....	...	....	.....	U. S. B.	Compressed ordnance-bronze.
37	.....	90.00	10.00	.....	.....	8.875	.....	.....	.....	....	.....	.....	....	...	....	.....	De.	After repeated compression.
38	.....	90.00	10.00	.....	.....	8.935	.....	.....	.....	....	.....	.....	....	...	....	.....	Ri.	Railroad-car bearings.
39	.....	90.00	10.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	B.	Ordnance-metal.
40	.....	89.30	10.70	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	B.	Small bar cast in iron mould.
41	.....	89.29	10.71	.....	.....	8.953	.....	.....	37,688	....	.....	.....	....	...	....	.....	Wa.	Small bar cast in clay mould.
42	.....	89.29	10.71	.....	.....	8.313	.....	.....	25,783	...	.....	.....	....	...	....	.....	Wa.	Mean of 12 gun-heads.
43	.....	89.29	10.71	.....	.....	8.353	.....	.....	26,011	....	.....	.....	....	...	....	.....	Wa.	Ordnance-metal.
44	.....	89.23	10.77	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	B.	
45	$SnCu_{18}$	89.00	11.00	.....	.....	8.84	.....	.....	.....	....	.....	.....	....	...	....	.....	Ri.	
46	$SnCu_{18}$	88.97	11.03	.....	.....	8.825	.....	.....	.....	....	.....	772.92	....	...	....	.....	C. J.	Mean of 83 gun-heads.
47	.....	88.89	11.11	.....	.....	8.523	.....	.....	29,655	....	.....	.....	....	...	....	.....	Wa.	
48	.....	88.39	11.61	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	12.10	Ma.	Gun-metal.
49	.....	88.00	12.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	La.	
50	.....	87.65	12.35	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	10.15	Ma.	
51	.....	87.50	12.50	.....	.....	8.643	Grayish yel.	Earthy	31,100	....	7.3	.....	....	...	....	.....	U. S. B.	
52	.....	86.80	12.40	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	W.	
53	$SnCu_{12}$	86.57	13.43	87.15	12.73	{8.68·a / 8.943b}	{Mottled white and yellow}	Fine vesic.	29,430	....	13.9	.....	....	...	....	.....	U. S. B.	{a Specific gravity of bar. b Specific gravity of fine turnings.}
54	.....	86.21	13.79	.....	.....	8.87	.....	.....	.....	....	.....	.....	....	...	....	.....	W.	Densest of all alloys (?) (Riche).
55	.....	86.00	14.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	.....	W.	Axle-bearing Seraing locomotive.
56	.....	85.71	14.29	.....	.....	.....	.....	.....	44,071	...	.....	.....	..	....	....	.....	Mus.	
57	.....	85.09	14.91	.....	.....	.....	.....	.....	.....	....	.....	.....	....	...	....	8.82	Ma.	
58	$SnCu_{10}$	84.33	15.67	.....	.....	8.87	.....	.....	.....	....	.....	.....	....	...	....	.....	Ri.	
59	.....	84.39	15.68	.....	.....	8.832	.....	.....	.....	....	.....	916.66	....	...	....	.....	C. J.	
60	.....	84.29	15.71	.....	.....	8.502	Reddish yel., 1	Fine cryst.	36,064	2	.....	8	6	15	....	.....	Mi.	

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 200.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
61	.....	84.00	16.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	..	.....	.....	B.	Axle-bearings.
62	.....	83.30	16.70	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	B.	Jewelers' punches.
63	$SnCu_9$..	82.81	17.19	.....	.....	8.462	Reddish yel., 2	Fine cryst.	34,048	3	.....	5	7	14	...	.....	Mi.	
64	....	82.50	17.50	.....	.....	8.792	Reddish gray	"	36,200	....	0.32	.....	...	...	....	... ..	U. S. B.	Strongest of series.
65	.....	82.00	18.00	.....	... ..	8.927	.....	.....	.....	....	.....	.....	....	.....	....	.....	R.	Annealed and tempered.
66	$SnCu_8$..	81.15	18.85	.....	.....	8.86	.....	.....	.....	....	.....	.....	....	..	....	.....	Ri.	
67	$SnCu_n$..	81.20	18.90	.....	.....	8.459	Yel'wish red, 2	Fine cryst.	32,648	4	.....	4	10	13	....	.....	Mi.	
68	.....	.....	.....	80.43	19.57	8.953	.....	.....	.....	....	.....	.....	....	.....	....	.....	Th.	Chinese gong.
69	.....	81.00	20.00	.....	.....	8.7	.....	.....	.....	....	.....	.....	....	.....	....	.....	B.	Bells of Reichenhall, 300 years old.
70	.....	80.00	20.00	.....	.....	.....	.....	.....	35,739	....	.....	.....	....	.....	....	.....	Mus.	
71	.....	80.00	20.00	.....	.....	8.850	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	Annealed and tempered.
72	.....	80.00	20.00	.....	.....	8.955	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	After repeated compression.
73	.....	80.00	20.00	80.95	18.84	8.740	Reddish gray	Fine gran.	32,980	....	0.40	.....	....	.....	....	.....	U. S. B.	
74	.....	79.20	20.80	.....	.....	8.927	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	Annealed and tempered.
75	$SnCu_7$..	79.02	20.98	.....	.....	8.90	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	
76	$SnCu_7$..	78.97	20.03	.....	.....	8.728	Yel'wish red, 1	Vitr. conch.	30,464	5	.....	3	11	12	....	.....	Mi.	
77	.....	78.00	20.00	.....	.....	.....	.....	.....	.....	....	.....	.....	....	.....	....	.....	B.	Best bell-metal.
78	....	77.50	22.50	.....	.....	8.917	Pinkish gray	Fine gran.	24,650	....	0.03	.....	....	.....	....	.....	U. S. B.	
79	$SnCu_4$..	76.32	23.68	76.64	23.24	8.565	.....	Smooth	22,010	....	0.02	.....	....	.....	....	.....	U. S. B.	
80	$SnCu_4$..	76.31	23.69	.....	.....	8.91	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	
81	$SnCu_4$..	76.29	23.71	... ..	.....	8.750	Bluish red	Vitreous	21,728	0	.....	2	12	11	....	.....	Mi.	
82	.....	76.20	23.80	.....	.....	9.1(?)	.....	.....	.....	....	.....	.....	....	.....	....	.....	B.	Church bell in Reichenhall, 600 years old.
83	.....	75.20	24.80	.....	.....	.....	.....	.....	.....	....	.....	.....	....	.....	....	.....	B.	Swiss clock bells, brittle.
84	. ....	75.00	25.00	.....	.....	8.879	Reddish white	.....	.....	....	.....	.....	....	.....	....	.....	W.	
85	$SnCu_3$..	42.91	27.09	.....	.....	8.87	.....	.....	.....	....	.....	.....	....	.....	....	.....	Ri.	
86	$SnCu_2$..	72.90	27.10	.....	.....	8.965	.....	.....	...	....	.....	Broke	....	....	20.7	.....	C. J.	

87	$SnCu_3$..	72.80	27.20	.....	.....	8.575	Bluish red	Conchoidal	10,976	0	.....	1	13	10	....	.....	Ml.		
88	.....	72.50	27.50	.....	.....	8.925	Reddish white	Conchoidal	6,493	....	0.003	.....	.....	.....	....	.....	U. S. B.		
89	.....	70.00	30.00	69.84	29.89	8.932	White	Conchoidal	5,585	....	0 008	.....	.....	.....	....	.....	U. S. B.	Mirror of telescope.	
90	.....	68.82	31.18	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Ri.		
91	$SnCu_4$..	68.28	31.72	.....	.....	8.80	.....	.....	.....	....	.....	.....	.....	.....	....	.....	C. J.		
92	$SnCu_4$..	68.27	31.73	.....	.....	8.948	.....	.....	.....	....	.....	.....	.....	.....	....	.....	U. S. B.		
93	$SnCu_4$.	68.25	31.75	68.58	31.26	8.933	White	Conchoidal	1,620	....	.....	Broke	.....	.....	....	15.5	.....		
94	$SnCu_4$..	68.21	31.79	.....	.....	8.400	Ash gray	Conchoidal	1,568	....	.....	6	14	9	....	.....	Ml.		
95	.....	63.21	31.70	.....	.....	.....	.....	.....	.....	0	.....	.....	.....	.....	....	.....	B.	Mirror metal.	
96	.....	67.90	32.50	.....	.....	8.907	White	Conchoidal	2,536	....	0.009	.....	.....	.....	....	.....	U. S. B.		
97	.....	66.67	33.33	.....	.....	.....	Steel gray	.....	.....	....	.....	.....	.....	.....	....	.....	W.	Hard, uniform.	
98	.....	66.67	33.33	.....	.....	.....	.....	.....	1,017	....	.....	.....	.....	.....	....	.....	Mus.		
99	.....	65.00	35.00	65.34	34.47	8.917	Bluish gray	.....	2,201	....	0.002	.....	.....	.....	....	.....	U. S. B.		
100	.....	62.50	37.50	.....	.....	8.956	Dark gray	Rad. cryst.	1,561	....	0.001	.....	.....	.....	....	.....	U. S. B.		
101	$SnCu_3$..	61.79	38.21	.....	.....	8.954	.....	.....	.....	....	.....	Broke	.....	.....	....	47.4	C. J.		
102	$SnCu_3$..	61.79	38.21	.....	.....	8.96	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Ri.		
103	$SnCu_3$..	61.71	38.29	.....	..	8.970	Dark gray	Rough, stony	688	....	0.003	.....	.....	.....	....	.....	U. S. B.	Greatest density, weakest.	
104	$SnCu_3$..	61.69	38.31	.....	.....	8.539	Dark gray	Tabul'r cryst.	1,120	0	.....	7	16	8	....	.....	Ml.		
105	.....	60.00	40.00	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	....	.....	B.	White bell-metal.	
106	.....	57.90	42.50	.....	.....	8.781	Light gray	Stony.	1,377	....	0.001	.....	.....	.....	....	.....	U. S. B.		
107	Sn_8Cu_{12}	56.32	43.68	56.70	43.17	8.682	"	"	1,455	....	0.003	.....	.....	.....	....	.....	U. S. B.		
108	.....	52.50	47.50	.....	.....	8.643	.....	.....	.....	....	0.001	.....	.....	.....	....	.....	U. S. B.	Weakest under transverse stress.	
109	$SnCu_2$..	51.84	48.16	.....	.....	8.57	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Ri.		
110	$SnCu_2$..	.....	... ..	.....	.....	8.512	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Cr		
111	$SnCu_2$..	51.83	48.17	.....	.....	8 533	.....	.....	.....	....	.....	Broke	.....	.....	....	42.8	C. J.		
112	$SnCu_2$..	51.80	48 20	51.62	48.09	8.560	Light gray	.....	2.555	....	0.003	.....	.....	.....	....	.....	U. S. B.	Remarkable for liquation.	
113	$SnCu_2$..	51.75	48.25	.....	.....	8.416	Grayish white	Vit. conch.	3,808	0	.....	9	15	7	....	.....	Ml.		
114	.....	50.00	50.00	.....	.....	.....	.....	.....	725	....	.....	.....	.....	.....	....	.....	Mus.		
115	.....	50.00	50.00	.....	.....	8.79	Bluish white	.....	.....	....	.....	.....	.....	.....	....	.....	W.	Very slightly malleable.	
116	Sn_7Cu_8.	47.95	52.05	47.61	52.14	8.442	Grayish white	Fine grain	1,525	....	0.003	.....	.....	.....	....	.....	U. S. B.		
117	.....	47.50	52.50	.....	.....	8.446	"	Crystal	2,407	....	0.003	.....	.....	.....	....	.....	U. S. B.		
118	Sn_3Cu_8.	44.67	55.33	.....	.....	8.30	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Ri.		
119	Sn_3Cu_8.	44.63	55.37	44.52	55.28	8.312	Grayish white	Crystal	3,010	....	0.003	.....	.....	.....	....	.....	U. S. B.		
120	.....	42.50	57.50	.....	.....	8.437	"	"	2,098	....	0.006	.....	.....	.....	....	.....	U. S. B.		
121	Sn_3Cu_4.	41.74	58.26	42.38	57.30	8.302	"	"	3,910	....	0.007	.....	.....	.....	....	.....	U. S. B.		
122	.....	40.00	60.00	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	....	.....	B.	White bell-metal.	
123	Sn_6Cu_8.	39.20	60.80	38.37	61.32	8.182	Grayish white	Crystal	2,820	....	0.005	.....	.....	.....	....	.....	U. S. B.		
124	.....	37.50	62.50	.....	.....	8.101	"	"	2,400	....	0.004	.....	.....	.....	....	.....	U. S. B.		
125	SnCu ..	34 99	65.01	.....	.....	8.12	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Ri.		
126	SnCu ..	34.98	65.02	... ..	.....	7.992	.....	.....	.....	....	.....	Broke	.....	.....	....	41.5	C. J.		
127	SnCu ..	.....	.....	.....	.....	8.072	.....	.....	.....	....	.....	.....	.....	.....	....	.....	Cr.		
128	SuCu ..	34.95	65.05	34.22	65.80	8.013	Grayish white	Crystal	3,371	....	0.005	.....	.....	.....	....	.....	U. S. B.		
129	SnCu ..	34.92	65.08	.....	.....	8.056	"	Tabul'r cryst.	3,136	0	.....	11	9	6	....	.....	Ml.		
130	.....	33.33	66.67	.....	.....	... .	White	.....	.....	....	.....	.....	.....	.....	....	.....	W.	Brittle; uniform.	
131	.....	32.50	67.50	.....	.....	7.931	Grayish white	Crystal	2,322	....	0.014	.....	.....	.....	....	.....	U. S. B.		

PROPERTIES OF ALLOYS OF COPPER AND TIN.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
132	Sn_4Cu_9.	28.72	71.28	25.85	73.80	7.918	Grayish white	Crystal	1,648	....	0.071	.....	....	....	....	.....	T.	
133	.....	27.50	72.50	.....	.....	7.915	"	"	4,380	....	0.018	.....	....	....	....	.....	T.	
134	.....	25.00	75.00	.....	.....	7.813	Bluish white	"	.....	....	.....	.....	....	....	....	.....	W.	
135	Sn_8Cu_3.	24.38	75.62	23.35	76.29	7.835	Grayish white	Fine cryst.	6,775	....	0.03	.....	....	....	....	.....	T.	
136	.....	22.50	77.50	.....	.....	7.774	"	"	5,000	....	0.12	.....	....	....	....	.....	T.	
137	.....	21.74	78.26	21.38	77.63	7.53	Whitish	.....	.....	....	.....	.....	....	....	....	.....	W.	Yellow, greenish white, shining.
138	Sn_2Cu..	21.21	78.79	.....	.....	7.738	.....	.....	.....	....	.....	135.42	....	....	43.1	.....	C. J.	
139	Sn_2Cu..	21.21	78.79	.....	.....	7.74	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	
140	Sn_2Cu..	21.18	78.82	20.25	79.63	7.770	Grayish white	Crystal	4,337	....	0.06	.....	....	....	....	.....	T.	
141	Sn_2Cu..	21.15	78.85	.....	.....	7.387	"	Coarse cryst.	8,730	0	.....	12	8	5	....	.....	Mi.	
142	Sn_8Cu_3.	17.68	82.32	.....	.....	7.652	.....	.....	.....	....	.....	.....	....	....	....	.....	Cr.	
143	.....	17.50	82.50	.....	.....	7.690	Grayish white	Crystal	2,816	....	0.20	.....	....	....	....	.....	T.	
144	.....	16.40	83.60	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	....	12.76	Ma.	
145	Sn_3Cu..	15.21	84.79	.....	.....	7.53	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	
146	Sn_3Cu..	15.21	84.79	.....	.....	7.605	.....	.....	.....	....	.....	104.17	....	....	42.3	.....	C. J.	
147	Sn_3Cu..	15.29	84.81	15.08	84.62	7.657	Grayish white	Crystal	6,520	....	0.92	.....	....	....	....	.....	T.	
148	Sn_3Cu..	15.17	84.83	.....	.....	7.447	"	Coarse cryst.	6,944	0	.....	13	15	4	....	.....	Mi.	
149	.....	12.50	87.50	.....	.....	7.543	"	Crystal	3,798	....	4.71	.....	....	....	....	.....	T.	
150	Sn_4Cu..	11.86	88.14	.....	.....	7.558	.....	.....	.....	....	.....	95.81	....	....	40.6	.....	C. J.	
151	Sn_4Cu..	11.84	88.16	11.49	88.47	7.552	Grayish white	Crystal	6,380	....	7.03	.....	....	....	....	.....	T.	
152	Sn_4Cu..	11.84	88.16	.....	.....	7.50	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	
153	Sn_4Cu..	11.82	88.18	.....	.....	7.472	Grayish white	Coarse cryst.	6,944	8	.....	14	4	3	....	.....	Mi.	
154	Sn_5Cu..	9.73	90.27	.....	.....	7.517	.....	.....	.....	....	.....	83.33	....	....	39.6	.....	C. J.	
155	Sn_5Cu..	9.73	90.27	.....	.....	7.52	.....	.....	.....	....	.....	.....	....	....	....	.....	Ri.	
156	Sn_5Cu..	9.70	90.30	8.57	91.30	7.487	Grayish white	Granular	6,450	....	23.47	.....	....	....	....	.....	T.	
157	Sn_5Cu..	9.68	90.32	.....	.....	7.442	"	Earthy	3,360	6	.....	15	3	2	....	.....	Mi.	
158	.....	9.09	90.91	.....	.....	7.472	.....	.....	.....	....	.....	.....	....	....	....	.....	W.	Slightly malleable.
159	.....	7.50	92.50	.....	.....	7.417	Grayish white	Granular	6,069	....	40.06	.....	....	....	....	.....	U. S. B.	

160	.....	6.43	93.57	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.03	Ma.
161	$Sn_{12}Cu$.	4.29	95.71	3.78	96.32	7.360	Grayish white	Granular	4,780	....	56.77	.....	.....	.....	.....	.....	U. S. B.
162	.....	2.50	97.50	.....	.....	7.342	"	Fibrous	5,600	....	121.9	.....	.....	.....	.....	.....	U. S. B.
163	$Sn_{48}Cu$.	1.11	98.89	0.74	99.08	7.305	"	"	3,650	....	133.9	.....	.....	.....	.....	.....	U. S. B.
164	$Sn_{96}Cu$.	0.56	99.44	0.32	99.46	7.299	"	"	4,475	....	208.8	.....	.....	.....	.....	.....	U. S. B.
165	Sn	0	100	.....	.....	7.293	"	"	3,500	....	219.8	.....	.....	.....	.....	.....	U. S. B.
166	.....	0	100	.....	.....	7.291	White	"	6,040	7	.....	16	1	1	....	.....	Mi.
167	.....	0	100	.....	.....	7.297	.....	.....	2,122	....	.....	.....	.....	.....	.....	.....	Wa.
168	.....	0	100	.....	.....	7.294	.....	.....	.....	....	.....	.....	.....	.....	.....	11.45	Ma.
169	.....	0	100	.....	.....	7.305	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Cr.
170	.....	0	100	.....	.....	.....	.....	.....	.....	....	.....	27	....	....	42.2	.....	C. J.
171	.....	0	100	.....	.....	.....	.....	.....	.....	....	.....	.....	....	....	15.2	17.0	We.

List of Authorities.

Abbreviations.

B.—Bolley. *Essais et Recherches Chimiques*, Paris, 1869, pp. 345, 348.

Cr.—Croockewit. *Erdmann's Journal*, 1848, vol. 45, pp. 87–93.

C. J.—Calvert and Johnson. Specific Gravities, *Phil. Mag.*, 1859, vol. 18, pp, 354-359; Hardness, *Phil. Mag.*, 1859, vol. 17, pp. 114–122; Heat Conductivity, *Phil. Trans.*, 1858, pp. 349–368.

De.—S. B. Dean. *Ordnance Notes*, No. XL., Washington, 1875.

La.—Lafond. *Dingler's Journal*, 1855, vol. 135, p. 269.

Mi.—Millit. *Phil. Mag.*, 1842, vol. 21, pp. 66–68.

Ma.—Matthiessen. *Phil. Trans.*, 1860, p. 161; *ibid.*, 1864, pp. 167–200.

Mar.—Marchand and Scheerer. *Journal für Praktische Chemie*, vol. 27, p. 193 (Clark's "*Constants of Nature*").

Mus.—Muschenbroek. *Ure's Dictionary*, article "Alloy."

Ri.—Riche. *Annales de Chimie*, 1873, vol. 30, pp. 351–419.

U. S. B.—*Report of Committee on Metallic Alloys of United States Board appointed to test iron, steel, etc.* (Thurston's determinations).

T.—Thomas Thomson. *Ann. de Chimie*, 1814, vol. 89, pp. 46–58.

W.—Watts's *Dictionary of Chemistry* (compiled from several authorities).

Wa.—Major Wade, United States Army. *Report on Experiments on Metals for Cannon*, Phila., 1856.

We.—Weidemann. *Phil. Mag.*, 1860, vol. 19, pp. 243, 244.

CHAPTER IX.

THE BRASSES AND OTHER COPPER-ZINC ALLOYS.

Brass is a term which is applied by many, and especially older, authors indifferently to all alloys composed principally of copper, combined with either tin or zinc. The alloy of copper and tin and its minor modifications are now becoming better known as bronze, and the name brass is generally restricted to the designation of alloys consisting mainly of copper and zinc. "Brass" ordnance is properly called *bronze* ordnance, and the compositions used in the bearings of machinery, which are usually of somewhat similar composition, are also properly called bronzes. The alloys of copper, tin and zinc, which occupy intermediate positions between the bronzes and the brasses, are as often known by the one name as by the other.

Copper and Zinc together form "Brass," which is usually made nearly in the proportion, copper, 66⅔, zinc 33⅓. Brasses of certain other proportions have specific names, as Tourbac, Pinchbeck. The mixture and fusion of the metals must be so conducted that the loss of zinc by volatilization may be the least possible; there is always some loss, and it may not only be serious as a matter of cost, but the introduction of oxides into the alloy is exceedingly injurious to its quality. The fusion is generally performed in crucibles heated in air-furnaces.

The change of color and of other qualities with the introduction of zinc is gradual and very similar in character to that produced by the admixture of tin; but the quantity of zinc demanded to produce the same modification is about twice as much as of tin. On adding zinc, the deep red color of copper is changed at once, becoming lighter and lighter,

and finally shading into a grayish white and then assuming more of the color of zinc. The alloy generally increases in hardness and loses ductility as the percentage of zinc is increased, up to a maximum, which being passed, ductility increases again. The most ductile are, however, those which contain 70 to 85 per cent. copper, 30 to 15 of zinc, the first being called "tombac," the latter "brass."

Mallet's Classification.—The following is Mallet's table of the copper-zinc alloys:

PROPERTIES OF COPPER-ZINC ALLOYS.

AT. COMP.	COPPER	S. G.	COLOR.	FRACT.	TENACITY.	ORDER OF		
						Mall.	Hard.	Fus.
Cu : Zn	by anal. per ct.				Tons per sq. in.			
1 : 0	100.	8.667	red	.....	24.6	8	22	15
10 : 1	98.80	8.625	red-yellow	coarse	12.1	6	21	14
9 : 1	90.72	8.607	"	fine	11.5	4	20	13
8 : 1	88.60	8.633	"	"	12.8	2	19	12
7 : 1	87.30	8.587	"	"	13.2	0	18	11
6 : 1	85.40	8.591	yellow-red	fine fibre	11.1	5	17	10
5 : 1	83.02	8.415	"	"	13.7	11	16	9
4 : 1	79.65	8.448	"	"	14.7	7	15	8
3 : 1	74.58	8.397	pale yellow	"	13.1	10	14	7
2 : 1	66.18	8.299	deep "	"	12.5	3	23	6
1 : 1	49.47	8.230	" "	coarse	9.2	12	12	6
1 : 2	32.85	8.263	dark "	"	19.3	1	10	6
8 : 17	31.52	7.721	silver white	"	2.1	very brittle	5	5
8 : 18	30.36	7.836	silver white	"	2.2	"	6	5
8 : 19	29.17	7.019	light gray	"	0.7	"	7	5
8 : 20	28.12	7.503	ash "	vitreous	3.2	brittle	3	5
8 : 21	27.10	8.058	light "	coarse	0.9	"	9	5
8 : 22	26.24	7.882	" "	"	0.8	"	1	5
8 : 23	25.39	7.443	ash "	fine	5.9	slight duct. brittle	1	5
1 : 3	24.50	7.449	" "	"	3.1	"	2	4
1 : 4	19.65	7.371	" "	"	1.9	"	4	3
1 : 5	16.36	6.605	dark "	"	1.8	"	11	2
0 : 1	0.	6.895	.....	.....	15.2	.....	23	1

In the above table, the minimum of hardness and fusibility is denoted by 1.

The conclusion of Storer * that these alloys are mixtures rather than true compounds, is accepted by Watts and other authorities.

Uses of Brass.—*Brass* is the alloy commonly employed in the arts in the construction of scientific apparatus,

* Mem. Am. Acad., N. S., vol. viii, p. 97.

mathematical instruments, and small parts of machinery. It is cast into parts of irregular shape, drawn into wire, or rolled into rods and sheets. It is harder than copper, very malleable and ductile, and can be "struck up" in dies, formed in moulds, or "spun" into vessels of a wide variety of forms if handled cold or slightly warm; it is brittle at a high temperature. A common proportion for making brass is copper 66, zinc 34. This alloy is a much slower conductor of electricity and of heat than copper, is more fusible, oxidizes very slowly at low temperatures, but rapidly at a high heat.

The brass of Romilly, which works remarkably well under the hammer, is composed of copper 70, zinc 30; English brass is often given 33 per cent. zinc, and for rolled brass 40 per cent. This constitutes "Muntz sheathing metal," as patented by G. F. Muntz in 1832. The proportion of zinc ranges, however, for such purposes, from 37 to 50 per cent. copper 63 to 50.

Muntz Metal is thus described by its inventor:—"I take that quality of copper known in the trade by the appellation of 'best selected copper,' and that quality of zinc, known in England as 'foreign zinc,' and melt them together in the usual manner in any proportion between 50 per cent. of copper to 50 per cent. of zinc, and 63 per cent. of copper to 37 per cent. of zinc, both of which extremes, and all intermediate proportions, will roll and work at a red heat; but as too large a proportion of copper increases the difficulty of working the metal, and too large a proportion of zinc renders the metal too hard when cold, I prefer the alloy to consist of about 60 per cent. of copper to 40 per cent. of zinc. This compound I cast into ingots of any convenient weight, and then heat them to a red heat, and roll or work them while at that heat into bolts and other like ship's fastenings, in the same manner as copper is rolled or worked, but only taking care not to overheat the metal so as to produce fusion, and not to put it through the rolls or work it after the heat has left it too much, say, when the red heat goes off."

This alloy is cast into ingots, and rolled, hot, into sheets,

which are cleaned by pickling and washed before they are sent into the market. As this alloy is cheaper and more durable than copper sheathing, and equally effective, it has displaced the latter almost entirely in the protection of wooden ships. When made on a large scale, the alloy is melted in a reverberatory furnace.

Special Properties.—Farmer has deposited brass by electrolysis and obtained an alloy containing copper 75, zinc 25, as ductile and malleable as rolled brass.

The brasses, or copper-zinc alloys, although probably of more extended use than the bronzes or copper-tin alloys, are not as well studied as the latter.

The metals, as already stated, p. 288, mix in all proportions, and produce alloys of which the general character has been shown in the introductory chapter of this part of the work and in the earlier paragraphs of this chapter.

The red color of copper, in this series, fades into yellow very gradually, and becomes golden-yellow at about 40 per cent. zinc; the color then becomes lighter, and at 60 per cent. zinc is bluish-white or silvery. With the change of color occurs the same change of strength and ductility noted with the copper-tin alloys, but it requires about twice as much zinc as tin to produce it. The white metals richest in copper are, like those of the bronze class, too brittle to be of use in engineering construction, but the yellow metals obtained with from 40 to 50 per cent. zinc are very valuable.

Brass has a high coefficient of expansion, 0.000054 to 0.000056 per Cent. degree (0.00003 to 0.000033 per degree F.).* Yellow brass fuses at from 1,870° F. (1,021° C.), and other compositions from 1,000° F. (550° C., nearly) to 2,000° F. (1,100° C., nearly), and loses strength and ductility as its temperature rises. The composition of the several most useful brasses is given elsewhere. Brass for fine work is often made of copper, 80; zinc, 17; tin, 3; "fine brass" of 2 copper, 1 of zinc; sheet brass of 3 copper, 1 zinc. A hard solder is made of 3 parts brass to 1 of zinc, etc., etc. Castings shrink in cooling $\frac{3}{16}$ inch to the foot (0.015).

* *Vide* Chapter I.

Hydrochloric acid reddens brass by dissolving its zinc; ammonia whitens it by taking up the copper.

Brass may be made tough and soft, hard and brittle, strong or weak, elastic or inelastic, dull of surface or lustrous as a mirror, friable or nearly as malleable and ductile as lead, as may be desired, by varying its composition. No known material, perhaps not even excepting iron, can be given so wide a range of quality or so wonderful a variety of uses. All the common varieties are composed of 67 to 70 parts copper and 33 to 30 of zinc. A little lead is often added to soften and cheapen it and tin in small proportion to strengthen it.

Brass is subject to flow under stress, like all other metals of what the Author has called the "tin class," and it is not safe to leave heavy loads upon it. Weights should not usually be hung upon brass chains, or upon brass tie-rods. The alloy is capable of being considerably hardened by compression, as when rolled into sheets, or by wire-drawing, and becomes much stronger and is less liable to permanent change under load. Some compositions are very elastic and make good springs for intermittent and occasional use.

The thin sheet brass used for metallic cartridges and other purposes requiring a metal in this form of great strength combined with ductility, is subject, frequently, to a singular deterioration with age which seem to be partly a physical and partly a chemical change. It results, sometimes in a very brief interval, in the entire destruction of the essential properties of such forms of this alloy. This has been studied by Egleston, but the results of investigation are not yet fully known.

Weems has found * that a pressure of 4,000 tons (or tonnes) being applied to brass, in the endeavor to produce brass tubes by "squirting" as is usual with lead, causes a separation of the zinc, which issues as a zinc pipe, leaving the copper behind. This is considered a proof that this alloy is a mixture rather than a chemical compound.

Applications in the Arts.—Bronze and brass have innumerable uses in the arts: locks, keys, shields, escutcheons,

* *Lond. Engineer*, 1883.

hinges, journal-bearings, pump-plungers, screw propellers, all small parts of machinery, optical and other philosophical instruments, cabinet-makers' fittings, sheathing of ships. Even so-called copper castings usually contain a small amount of zinc—2 to 5 per cent., to give them soundness.

The copper and brass manufactures of the United States are very extensive and of excellent character, both as to material and workmanship, and in those departments which are purely mechanical, are probably unequalled elsewhere. The purest copper is at their doors and the best of zinc; while tin is likely, in time, to be largely produced in this country also.

Brass to be used in the rolling mill in the manufacture of sheet metal, is cast between marble blocks which are separated to a distance which determines the thickness of the ingot or slab. The marble is coated with a thin layer of loam prepared for the purpose; the sides are closed with moulding sand. The slabs, when cast, are rolled, several "passes" being necessary, and the sheets are annealed at intervals, and when finally finished are "pickled" to give them a good surface. For fine work, the surfaces must sometimes be repeatedly scraped during the process of rolling to remove surface impurities and defects.

Wire brass is similarly treated, and the plates are then slit into rods in the "slitting mill," rolled to give them a section which can be handled in the wire-mill, and the rods are then drawn as in making iron wire.*

Brass tubes for steam boilers, condensers and other purposes, are usually drawn, as are many other forms of section.

Working Brass.—Yellow brass, and several compositions of similar character, are so easily worked cold that many articles are made by "striking up" in a die, under a press or a drop-hammer. Where a considerable change of form is necessary, the work is done by a succession of operations alternating with annealing. Rolls may often be used to form brass into the desired shape and they are still oftener employed to impress a pattern on the sheet.

* See account of methods of wire-drawing.

"Spinning" is a peculiar and very interesting, as well as useful process. It is employed in altering the shape of a disk or of a cylinder which can be "chucked" and held in a lathe, while the tool of the workman, pressing on the edge, turns it over and forces it into a new shape.

Spinning brass often consists merely in forming a flat sheet, turning in the lathe, by the pressure of a smooth burnishing tool. Chasing is done with a graver, and matting and embossing with formers and hammers. In burnishing to give high lustre, the metal is kept wet with sour beer, while the burnisher by a steady friction produces the polish.

"Burnishing" consists in giving a fine lustrous surface by the pressure and friction of a smooth, highly polished steel tool, lubricated well, as above. The surface is first prepared by giving it a good polish by the usual methods. The "burnishers" are made of fine steel, carefully polished with crocus and oil, and kept in the most perfect possible condition.

The working of brass in the lathe requires especial care, not only in the handling, but also in the form of the tool. The cutting edge is given a much larger angle than in cutting iron and steel; hand-tools require to be given precisely the right inclination and a constant rotation; the velocity of cutting greatly exceeds that usual with iron.

Brass tubes are sometimes made by simply rolling sheet-brass, cut to exact size, upon a mandrel and brazing or soldering the joint; but they are more usually "drawn."

The roll and its mandrel are sent through the draw-plate together and the tube is thus drawn to size and the soldered lap becomes distinguishable only by the color of the joint.

Locomotive tubes, and others required to bear very high temperatures and pressures, are drawn solid and seamless.

Brass condenser tubes should be made of copper 70, zinc 30, as prescribed by the British Admiralty. Boiler tubes are made of copper 18, zinc 32. The metals should be pure.

In many cases peculiar and ornamental shapes are given by modification of the form of mandrel or of draw-plates. Patterned sheets are produced by the use of rolls with

properly cut surfaces. The "die" in which the metal is given shape under the blows of a "drop," or of a heavy hammer, is very extensively used in working brass.

The Properties of Brasses, as described by the best authorities, are exhibited in the most concise manner in the following table, which was originally collated for the Committee on Alloys of the U. S. Board,* as was that already given for the bronzes. It includes the results of work done for that board.

A more complete exhibit of the mechanical properties of the bronzes and brasses will be given in succeeding chapters describing investigations, usually conducted by the Author, as above.

* Report, vol. ii, 1881, p. 67.

PROPERTIES OF THE ALLOYS OF COPPER AND ZINC.

Comparison of several Authorities.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	100	0	.....	.....	8.874	Red	Fibrous	27,800	....	30.8	....	.....	....	.....	.....	U. S B.	
	100	0	.....	.....	8.667	Tile red	Earthy	55,104	8	.....	1	22	15	.....	.....	Ml.	
	100	0	.....	.....	8.921	.....	.....	.....	....	.....	....	.....	....	.....	93.16	Ma.	
	100	0	.....	.....	.....	.....	.....	.....	....	.....	....	30.1	....	81.1	.....	C. J.	
	100	0	.....	.....	8.952	.....	.....	.....	....	.....	....	.....	....	.....	.....	Mar.	Sheet copper.
	100	0	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	73.6	79.3	We.	
	100	0	.....	.....	8.672	.....	.....	24,252	....	.....	....	.....	....	.....	.....	We.	Mean of 9 samples.
	99.15	0.85	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Tombac for buttons.
	97.80	2.20	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	.....	Red tombac of Vienna.
	97.50	2.50	97.83	1.88	8.791	Yellow red	Vesicular	27,240	....	118.9	...	.....	....	.....	.....	U. S. B.	
	97.20	2.50	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Railway axle boxes, porous.
	95	5	96.07	3.79	8.825	Yellow red	Vesicular	11,500	....	37.9	...	.....	....	.....	.....	U. S. B.	Defective bar.
	93.6	6.4	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Pinchback.
	92.5	7.5	92.32	7.68	8.746	Yellow red	Vesicular	.....	....	.....	....	.....	....	.....	.....	U. S. B.	
	92.5	7.5	.....	.....	.....	.....	.....	.....	....	.....	...	.....	....	.....	.....	Bo.	Bearings, Austria.
	92	8	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Red tombac of Paris.
	91	9	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Tombac.
$Cu_{10}Zn$...	90.72	9.28	.....	.....	8.605	Red yellow	Coarse cryst.	27,104	6	.....	13	21	14	.....	.....	Ml.	
$Cu_{10}Zn$...	90.65	9.35	.....	9.60	8.834	.....	.....	.....	....	.....	....	.....	....	.....	.....	Rl.	Sp. gr. of ingot, 8.753.
	90	10	90.56	9.42	8.773	Yellow red	Vesicular	.....	....	69.1	....	.....	....	.....	.....	U. S. B.	
	90	10	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	French oreide.
Cu_9Zn ...	89.80	10.20	.....	.....	8.607	Red yellow	Finely cryst.	25,760	4	.....	11	20	13	.....	.....	Ml.	
	88.89	11.11	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	27.3	25.5	We.	
Cu_8Zn ...	88.60	11.40	.....	.....	8.633	Red yellow	Finely cryst.	28,672	2	.....	10	19	12	.....	.....	Ml.	

	87.50	12.50	88.94	10.97	.....	Yellow red	Vesicular	.....	....	.....	....	.....	....	.....	.....	U. S. B.	
Cu_7Zn ...	87.30	12.70	.....	.....	8.587	"	Finely cryst.	29,368	9	.....	9	18	11	.....	.....	Mi.	
	86.67	13.33	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	29.9	30.9	We.	
	86.38	13.62	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Very delicate castings.
	86	14	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Ornaments of Hanover.
	85.5	14.5	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	French oreide.
Cu_6Zn ...	85.4	14.6	.....	.....	8.591	Yellow red	Fine fibrous	31,584	5	.....	8	17	10	.....	.....	Mi.	
Cu_6Zn ...	85.34	14.66	.....	14.90	8.710	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of powder, 8.584.
	85.3	14.7	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Paris jewelry.
	85	15	89.80	10.06	8.656	Red yellow	Earthy	.....	....	250.1	....	.....	....	.....	.....	U. S. B.	
	85	15	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Tombac of Oker.
	84.6	15.4	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Gold leaf.
	84.21	15.79	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Tombac for buttons.
	83.99	17.1	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Bronze powder.
Cu_5Zn ...	83.02	16.98	.....	.....	8.415	Red yellow	Finely cryst.	30,688	11	.....	2	16	9	.....	.....	Mi.	Bath metal.
Cu_5Zn ...	82.95	17.05	.....	.....	8.673	.....	.....	.....	....	.....	....	427.08	....	71.5	.....	C. J.	
	82.54	17.46	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Alloy of jewelry.
	82.5	17.5	82.93	16.98	8.633	Red yellow	Earthy	32,600	....	105.3	....	.....	....	.....	.....	U. S. B.	
	82.46	17.54	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	31.1	29.2	We.	
	82.3	17.7	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Ornaments.
	80	20	181.91	17.90	8.598	Yellow	Earthy	32,670	....	113.1	....	.....	....	.....	.....	U. S. B.	
Cu_4Zn ...	79.65	20.35	.....	.....	.....	Yellow red	Finely cryst.	52,928	7	.....	3	15	8	.....	.....	Mi.	Dutch brass.
Cu_4Zn ...	79.56	20.44	.....	.....	8.650	.....	.....	.....	....	.....	....	468.75	....	66.6	.....	C. J.	
Cu_4Zn ...	79.51	20.49	.....	21.80	8.638	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of powder, 8.367.
	77.9	22.1	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Vienna gold-leaf.
	77.5	22.5	77.39	22.45	8.574	Yellow	Earthy	35,630	....	97.5	....	.....	....	.....	.....	U. S. B.	
	75.7	24.3	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Bristol metal.
	75	25	76.65	23.08	8.528	Yellow	Earthy	30,520	....	76.7	....	.....	....	.....	.....	U. S. B.	
	74.62	25.38	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Ship sheathing.
Cu_3Zn ...	74.58	25.42	.....	.....	8.377	Pale yellow	Finely cryst.	29,344	10	.....	4	14	7	.....	.....	Mi.	Rolled sheet brass.
Cu_3Zn ...	74.48	25.52	.....	.....	8.576	.....	.....	.....	....	.....	....	468.75	....	63.8	.....	C. J.	Brass of { 32 copper. 12 zinc.
	72.73	27.27	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	
	72.5	27.5	73.20	26.47	8.465	Yellow	Earthy	31,580	....	88.7	....	.....	....	.....	.....	U. S. B.	
	72	28	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Chrysorin.
	71.5	28.5	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Tombac.
	70.1	29.9	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forg'g or leaf.
	70	30	71.20	28.54	8.444	Yellow	Earthy	30,510	....	77.8	....	.....	....	.....	.....	U. S. B.	
	67.74	32.26	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	25.8	25.4	We.	
	67.54	32.46	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forging.
	67.5	32.5	69.74	30.06	8.384	Yellow	Earthy	28,120	....	49.1	....	.....	....	.....	.....	U. S. B.	
	67.2	32.8	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Bristol metal.
	66.7	33.3	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Chrysorin.
	66.6	33.4	.....	.....	.....	.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Common brass.
Cu_2Zn ...	66.18	33.82	.....	.....	8.299	Full yellow	Finely cryst.	28,000	3	.....	6	13	6	.....	.....	Mi.	
Cu_2Zn ...	66.16	33.84	.....	.....	8.392	.....	.....	.....	....	.....	....	.....	....	.....	.....	Cr.	
Cu_2Zn ...	66.06	33.94	.....	.....	8.488	.....	.....	.....	....	.....	....	472.92	....	62.1	.....	C. J.	

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	66	34	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forging.
	65.98	34.02	.....	34.50	8.410	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of powder, 8.390.
	65.4	34.6	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Good brass wire.
	65.3	34.7	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Mosaic gold.
	65	35	66.27	33.50	8.371	Red yellow	Earthy	37,800	....	72.8	....	.....	....	.....	.....	U. S. B.	
	65	34.76	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forging.
	63.5	36.5	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	" "
	62.5	37.5	63.44	36.36	8.411	Red yellow	Earthy	48,300	....	60.6	....	.....	....	.....	.....	U. S. B.	
	61.25	38.75	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Strong solder for brass.
	60.8	39.2	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Bristol metal.
	60.16	39.71	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forging.
	60	40	60.94	38.65	8.405	Red yellow	Earthy	41,065	....	49.0	....	.....	....	.....	.....	U. S. B.	
	60	40	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	.....	Muntz metal.
	59.5	40.5	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Ship-sheathing.
Cu_3Zn_2...	57.36	40.64	.....	.....	8.224	.....	.....	.....	....	.....	....	.....	....	.....	.....	Cr.	
Cu_3Zn_2...	59.26	40.74	.....	40.10	8.412	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of powder, 8.329.
	58.33	41.77	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Suitable for forging.
	57.5	42.5	58.49	41.10	8.363	Red yellow	Earthy	50,450	....	12.1	....	.....	....	.....	.....	U. S. B.	
	55	45	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Bath metal.
	55	45	55.15	44.44	8.283	Red yellow	Earthy	44,230	....	19.5	....	.....	....	.....	.....	U. S. B.	
	54.9	45.1	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	V'ry ductile brass (Storer).
	54	46	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	" "
	52.5	47.5	54.86	44.78	8.301	Red yellow	Coarsely gran.	46,400	....	7.4	....	.....	....	.....	.....	U. S. B.	
	50	50	49.66	50.14	8.291	"	"	30,990	....	3.1	....	.....	....	.....	.....	U. S. B.	
CuZn	49.47	50.53	.....	.....	8.230	Full yellow	Coarse cryst.	20,603	12	.....	5	12	6	.....	.....	Ml.	German brass.
CuZn	49.32	50.68	.....	.....	7.808	.....	.....	.....	....	.....	....	604.17	....	68.8	.....	C. J.	
CuZn	49.23	50.76	.....	50.30	8.304	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of ingot, 8.263.
	47.5	52.5	48.95	50.82	8.216	Pinkish gray	Coarsely gran.	26,050	....	0.36	....	.....	....	.....	.....	U. S. B.	
	45	55	47.56	52.28	.....	"	"	24,150	....	0.25	....	.....	....	.....	.....	U. S. B.	
	43	57	.....	.....		.....	.....	.....	....	.....	....	.....	....	.....	.....	Bo.	Escutcheons of locks.
	42.5	57.5	43.36	56.22	8.034	Pinkish gray	Finely gran.	9,170	....	0.02	....	.....	....	.....	.....	U. S. B.	
	40	60	41.30	58.12	8.001	Silver white	Vitreous conch.	3,727	....	0.01	....	.....	....	.....	.....	U. S. B.	
Cu_2Zn_3...	39.27	60.73	.....	60.35	8.171	.....	.....	.....	....	.....	....	.....	....	.....	.....	Ri.	Sp. gr. of ingot, 8.039.
	37.5	62.5	38.36	61.05	7.982	Silver white	Vitreous conch.	3,087	....	0.02	....	.....	....	.....	.....	U. S. B.	
Cu_1Zn_3...	36.88	63.12	.....	.....	7.939	.....	.....	.....	....	.....	....	.....	....	.....	.....	Cr.	
	35	65	36.62	62.78	7.974	Silver white	Vitreous conch.	2,656	....	0.006	....	.....	....	.....	.....	U. S. B.	

	33.34	66.66	...	.....	8.283	Deep yellow	Coarse cryst.	43,232	1	.....	7	10	6	.....	.....	Bo.	Strong solder for brass.
$CuZn_6$ ...	32.85	67.15	.....	.....	7.859	.....	.....	.....	.....	.....	.....	Broke	....	42.8	.....	Ml.	Watchmakers' brass.
$CuZn_5$ ...	32.74	67.26	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	C. J.	
$CuZn_3$ ...	32.00	67.34	.....	64.80	8.048	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Ri.	Sp. gr. of ingot, 7.796.
	32.5	67.5	35.68	63.71	7.966	Silver white	Vitreous conch.	2,397	....	0.11	....	.....	.....	.....	.....	U. S. B.	
Cu_4Zn_{17}..	31.52	68.48	.....	.....	7.721	"	Conchoidal	4,704	0	.....	22	5	5	.....	.....	Ml.	Very brittle.
Cu_2Zn_{10}..	30.30	69.70	.....	.....	7.836	"	Vitreous conch.	4,928	0	.....	23	6	5	.....	.....	Ml.	"
	30	70	32.94	66.23	7.811	"	"	1,774	....	0.005	....	.....	.....	.....	.....	U. S. B.	
Cu_4Zn_{19}..	29.17	70.83	.....	.....	8.019	Silver gray	Conchoidal	1,568	0	.....	21	7	5	.....	.....	Ml.	Very brittle.
Cu_2Zn_{20}..	28.12	71.88	.....	.....	7.603	Ash gray	Vitreous	7,168	0	.....	19	3	5	.....	.....	Ml.	Brittle.
	27.5	72.5	29.20	70.17	7.766	Light gray	"	6,414	....	0.109	....	.....	.....	.....	.....	U. S. B.	
Cu_4Zn_{21}..	27.10	72.90	.....	.....	8.058	Silver gray	Conchoidal	2,016	0	.....	18	9	5	.....	.....	Ml.	Brittle.
Cu_6Zn_{22}..	26.24	73.76	.....	.....	7.882	"	"	1,792	0	.....	20	8	5	.....	.....	Ml.	Very brittle.
	25.4	74.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Bo.	Protect iron from rust.
Cu_4Zn_{23}..	25.39	74.61	.....	.....	7.443	Ash gray	Finely cryst.	13,216	0	.....	25	1	5	.....	.....	Ml.	Barely malleable.
	25	75	.....	.....	7.675	Bluish gray	Finely gran.	9,680	....	0.002	....	.....	.....	.....	.....	U. S. B.	
$CuZn_3$ ...	24.64	75.36	.....	.....	7.736	.....	.....	.....	.....	.....	.....	Broke	....	53.1	.....	C. J.	
$CuZn_3$ ...	24.50	75.5	.....	.....	7.449	Ash gray	Finely cryst.	11,424	0	.....	16	2	4	.....	.....	Ml.	Brittle.
	22.5	77.5	21.82	77.43	7.416	Bluish gray	Finely gran.	7,000	....	0.004	....	.....	.....	.....	.....	U. S. B.	
	20	80	20.81	77.63	7.418	"	"	9,000	....	0.002	....	.....	.....	.....	.....	U. S. B.	
	20	80	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Bo.	Metal for buttons.
$CuZn_4$ ...	19.65	80.35	.....	.....	7.372	Ash gray	Finely cryst.	4,256	0	.....	14	4	3	.....	.....	Ml.	White button metal.
$CuZn_4$ ...	19.57	80.43	.....	.....	7.445	.....	.....	.....	.....	.....	.....	Broke	....	58.9	.....	C. J.	
$CuZn_4$ ...	19.52	80.48	.....	79.30	7.863	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Ri.	Sp. gr. of ingot, 7.215.
	17.5	82.5	17.49	81.62	7.225	Bluish gray	Finely gran.	5,350	....	0.003	....	.....	.....	.....	.....	U. S. B.	
$CuZn_5$ ...	16.36	83.64	.....	.....	6.605	Very dark gray	Finely cryst.	4,032	0	.....	17	11	2	.....	.....	Ml.	Brittle.
$CuZn_5$ ...	16.30	83.70	.....	.....	7.442	.....	.....	.....	.....	.....	.....	Broke	....	59.5	.....	C. J.	
	15	85	14.19	85.10	7.163	Bluish gray	Finely gran.	8,500	....	0.004	....	.....	.....	.....	.....	U. S. B.	
	12.5	87.5	12.12	86.67	7.238	"	"	12,413	....	0.009	....	.....	.....	.....	.....	U. S. B.	
$CuZn_8$ ...	10.82	89.18	.....	89.90	7.315	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Ri.	Sp. gr. of ingot, 7.299.
	10	90	10.30	88.88	7.253	Bluish gray	Finely gran.	14,450	....	0.10	....	.....	.....	.....	.....	U. S. B.	
	7.5	92.5	7.20	92.07	7.131	"	"	10,650	....	8.04	....	.....	.....	.....	.....	U. S. B.	
	5	95	4.35	94.59	7.108	"	Finely cryst.	18,065	....	0.84	....	.....	.....	.....	.....	U. S. B.	
	2.5	97.5	2.45	96.43	7.080	"	Tab. cryst.	11,400	....	2.67	....	.....	.....	.....	.....	U. S. B.	
	0	100	.....	.....	7.143	Bluish white	"	5,400	....	26.51	....	.....	.....	.....	.....	U. S. B.	
	0	100	.....	.....	6.895	Bluish gray	"	34,048	13	.....	12	23	1	.....	.....	Ml.	Brittle.
	0	100	.....	.....	7.148	.....	.....	.....	.....	.....	.....	.....	.....	29.02	27.39	Ma.	
	0	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	62.8	.....	C. J.	
	0	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	28.1	27.3	We.	

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CHAPTER X.

THE KALCHOIDS AND MISCELLANEOUS ALLOYS.

Other Alloys than Bronzes and Brasses exist in immense variety and have numerous applications in the Arts, although of far less common application than the classes of alloys already described.

Of these alloys, the most important are those which most closely resemble the true bronzes and brasses in composition, as alloys consisting of bronze or brass with which are united smaller proportions of lead, iron, nickel, antimony, bismuth, and other common metals. In this class also fall the "*Kalchoids*," as the Author would call them, or the copper-tin-zinc alloys which are usually called brass or bronze accordingly as zinc or tin predominates. The white "anti-friction" or "anti-attrition" metals, the fusible alloys, and type and stereotype metals, all come within this classification.

The Kalchoids (Gr. *Kalchos*), or Copper-Tin-Zinc Alloys, are of great value and include the strongest, and probably the hardest, possible combinations of these metals. They are, in most respects, usually, intermediate between the brasses and the bronzes obtained by uniting two metals.

According to Margraff, these alloys are often very valuable and have the character as per table on next page.

Mackensie finds the alloy, copper 58, zinc 25, tin 17, excellent for castings and a good statuary bronze; and proposes copper 50, zinc 22, tin 28, for mirrors for telescopes; it is slightly yellow and takes a very fine polish. Bronzes in which equal parts tin and zinc are used are of common use for very small articles—as "brass" buttons. Knives for cotton printers' rolls are often made of copper 82, zinc 10, tin 8. Depretz' "chrisocalle" is of copper 92, tin 6, zinc 6,

it has a beautiful golden color. Another composition imitating gold is, copper 81.5, zinc 8, tin 0.5; and still another, which retains its lustre well, is of copper 80, zinc 17, tin 3; it is used for the small parts of ornamented pistols, etc. Alloys containing these metals are used for bronze medals, the zinc and tin being introduced to the extent of from 2 to 8 per cent. and the total of both being usually 10 per cent. or less. The percentage of zinc is usually kept under 3 or 4 in ordnance metal.

COPPER-TIN-ZINC ALLOYS.

NO.	COPPER.	TIN.	ZINC.	REMARKS.
1	100	100	100	Very white, brittle, subject to liquation.
2	100	50	50	" but finer grain.
3	100	25	50	Yellowish tint, hard, fine, not malleable.
4	100	25	25	Brittle.
5	100	20	20	Brittle, hard, yellow.
6	100	16	16	" " " close grained.
7	100	14	14	Yellow, slightly malleable.
8	100	12.5	12.5	" more malleable.
9	100	11	11	" " "
10	100	10	10	Fine yellow, fine grain, malleable.
11	100	8	8	Yellow, softer, more malleable.
12	100	7	7	Golden, malleable, soft.
13	100	6	6	" " "

The use of 8 to 15 per cent. of tin and 2 per cent. zinc in alloy with copper is probably as common as the employment of the bronzes without zinc; the latter is added to improve the color. Alloys of copper containing from 3 to 8 or 10 per cent. zinc and from 8 to 15 per cent. tin are used in engineering very extensively, the softer alloys for pump-work, the harder for turned work and for nuts and bearings. An alloy of 5 per cent. tin, 5 zinc and 90 copper is cast into ingots and remelted for general purposes. It is tough, strong and sound. Copper 75, tin 12, zinc 3 makes a good mixture for heavy journal-bearings. Copper 76, tin 12, zinc 12, is as hard as tempered steel and was made into a razor-blade by its

discoverer, Sir F. Chantrey.* When copper and brass are mixed in equal proportions and their sum is equal to the weight of tin, the alloy constitutes a solder.

Copper, Zinc and Iron unite with some difficulty, and the presence of iron is thought to make brass harder, to weaken it, and to increase its liability to tarnish. A ternary alloy of this character was introduced in England as early as 1822 and was claimed to be stronger and better for the presence of the iron. An alloy of 1 per cent. brass with 99 of iron was advised for castings exposed to corrosion, and Karsten found that it was harder than the cast iron, and considered it well adapted for use in steam engine cylinders and heavily loaded journal bearings. Herve found the zinc less desirable in copper-iron alloys than tin. He states that alloys containing 1.33 to 4 per cent. copper and 0.65 to 3 per cent. zinc were stronger than the cast iron with which they were alloyed. Sterro-metal, elsewhere described, is a metal of this kind, containing also a small amount of tin.

Copper, Tin and Iron may be alloyed to make a ferrous bronze of great value. The introduction of cast-iron into gun-bronze (copper 89, tin 11, or copper 90, tin 10) is not only useful, in small amounts as a flux, but this ferrous alloy is harder and stronger than the bronze alone. This alloy was made in Russian arsenals about 1820–5, and used for ordnance. The maximum proportion of iron was from 12 to 25 per cent., according to the use intended. The guns made of these alloys were found, according to Depretz, to excel good gun-bronze ordnance in strength and endurance. Similar alloys were made in France by the Messrs. Darcet † and by M. Dussaussoy, of the artillery, and on a large scale, in the government foundry at Douai.

The latter experiments were made with alloys containing:

Copper.	Tin.	Iron.	Copper.	Tin.	Iron.
90	10	6	90	10	4
90	10	3			

* Holtzapffel.

† Alliages Métalliques, p. 333.

The results were not such as to lead to the adoption of these alloys in making field guns.

Wrought iron was introduced into standard gun-bronze by Dussaussoy as early as 1817, using tin-plate for the purpose. When the proportion of iron exceeded 2 per cent. the result was not satisfactory. For small articles, the ferrous bronze was found an improvement, it being stronger, harder and less fusible. Gen. Goguel, of the Russian Army, added 12 per cent. of wrought iron to gun-bronze, and reported that the ordnance made of this alloy proved much superior to that made of common gun-bronze. Subsequently, an extended investigation was made by the order of the French government by MM. Gay Dussac and Darcet, and later by M. Herve of the French Artillery. The former research led to no result; the last named investigator concluded that the use of tin in securing an alloy of iron with copper is of advantage and that re-fusion is advisable to secure the best results.

Manganese Bronze is said to have qualities resembling those of phosphor-bronze, the introduction of manganese increasing the strength, ductility and homogeneousness of the alloy. The manganese alloys are usually white tinged with red, ductile, hard and tenacious. They are often known as white brass, white bronze or white alloys; they take a fine polish; those richest in copper have a decided rose hue. These alloys, as well as the phosphor-bronzes, are in somewhat extensive use, especially in Great Britain.

Copper and manganese alloy easily, or with difficulty, under different conditions, making a metal of considerable malleability, red in color, turning green when weather stained. It is less fusible than copper, lighter in color, and more liable to tarnish; it may be made by fusing together copper and the black oxide of manganese. Manganese bronze contains iron, also, and is made by melting together copper and spiegeleisen or "ferro-manganese." When containing 10 per cent. manganese, the alloy of copper and this metal is dense, grayish-white with a tinge of red, very ductile and malleable,

and of rather a short fracture; with 20 per cent. manganese, the color is silver-white to tin white, strong and ductile, with a fine lustre; with 30 per cent. manganese, the properties remain little altered; with 40 per cent., the alloy becomes iron-gray, malleable and ductile, very strong, fracture inclined to fibrous. Thus, according to Berthier, all these alloys are ductile, strong, compact and homogeneous.

Manganese-bronze is very similar in its general characteristics to phosphor-bronze; but is a white alloy and differs in being a triple compound of the metals, copper, tin and manganese, instead of an alloy of copper and tin fluxed with a metalloid. It possesses some peculiarities which give very great value to this metal as a material of construction. It is remarkably hard, tough and elastic, has rather a high elastic limit, as compared with ordinary bronze, and is found to be very durable when used for bearings of machinery. A common proportion of its constituents is, copper, 88, tin, 10, manganese, 2.

Preparation and Uses of Manganese-Bronze.—As described by the inventor, Mr. P. M. Parsons, white bronze, or manganese-bronze, is prepared by combining ferro-manganese, in different proportions, with various bronze alloys, thus producing qualities suited to various uses. The ferro-manganese is first subjected to a refining process, by which the silicon is eliminated, and the proportion between the iron and manganese adjusted in various degrees, for use according to the quality of bronze to be produced. To effect this combination, the temperature of the copper must be brought up to the melting point of the ferro-manganese, which is melted separately and then added in a fluid state.

The effect of this combination is similar to that produced by the addition of ferro-manganese to decarbonized iron in the Bessemer converter. The manganese in its metallic state having a strong affinity for oxygen, cleanses the copper of oxides, and renders the metal more dense and homogeneous. A portion of the manganese is utilized in this manner, while the remainder, with the iron, becomes permanently combined with the copper, and plays an important part in improving and modifying the quality of the bronzes prepared from the

copper thus treated, the effect being to increase their strength, hardness, toughness in various degrees, according to the quality and quantity of the ferro-manganese employed. Manganese, when once incorporated with the copper, is not driven off by remelting; the quality of the manganese-bronze is improved by remelting.

Manganese-bronze, as is stated, when forged, is remarkable for its strength and toughness, having an average tensile strength equal to mild steel, and elongating as much before breaking. It is suitable for forgings of all kinds, for bolts and nuts for engine and machine work, for ships' bolts, rudder and other fittings, screws, pins, nails, pump-rods, wire, and for all purposes for which yellow metal, brass, and copper are employed. In forging this metal, it should be heated to a clear cherry red (not bright), when it may be hammered, rolled, pressed, or worked in any way as long as it retains any color. It should not be worked at a black heat, but when the color is just fading it should be reheated.

In rolled sheets and plates it can be worked both hot and cold. In working hot, the instructions given for forgings should be followed. The metal can be rolled, stamped, pressed, and worked cold like brass or copper, being annealed as required. It is stronger, stiffer, and harder than copper, brass, or yellow metal, for which it can be substituted for purposes to which these are applied.

The rods, plates, sheets and angles are supplied of mild, medium, or high qualities, as required. The mild and medium qualities have a tensile strength of 28 tons per square inch (4,410 kgs. per sq. cm.), with an elastic limit at 40 per cent. and stretch from 28 to 45 per cent. before breaking. These qualities can be worked and riveted up cold, and are claimed to be greatly superior to yellow metal or gun metal.

When ships' screws are made of this material, they are given less thickness than when made of mild steel or of common bronze; it is not subject to alteration of form when taken from the mould or by the annealing which must be done with steel castings; it retains a clean surface remarkably well, but its cost is considerable.

The ferro-manganese used to mix with gun metal contains from 10 to 40 per cent. of metallic manganese; with brass alloys, 5 to 20 per cent., and with bronze alloys, the proportion lies between the above, according to the proportions of tin and zinc employed. To prepare ferro-manganese containing a given amount of metallic manganese, the inventor melts rich ferro-manganese, containing up to 70 per cent., in a crucible under powdered charcoal, and with a quantity of the purest wrought-iron scrap. If it is desired to employ a ferro-manganese to mix with any of the alloys containing 20 per cent. of manganese, a ferro-manganese containing 60 per cent. of metallic manganese, and, say, 1 per cent. of silicon, is melted with wrought-iron scrap, in the proportion of 100 of ferro-manganese to 300 scrap. Then a ferro-manganese containing 20 per cent. of metallic manganese will be obtained, in which there is only one-third of 1 per cent. of silicon.

Dry sand or loam moulds are recommended for casting. Metal moulds render the alloy somewhat harder and closer in texture.

Manganese-bronze is said to be much less subject to corrosion in salt water than is pure copper. Alloys containing from 75 to 85 per cent. copper are most usually adopted for machinery. Zinc often forms a constituent of these alloys, in the proportion of from 2 to 10 per cent.

The addition of manganese to bronzes and brasses gives them much lighter color, greater hardness and tenacity, without proportionally decreasing ductility and resilience. Copper and manganese alone form white alloys of great hardness, strength and ductility. Some of these alloys forge well and can be rolled with ease. They are somewhat susceptible to the action of the atmosphere at high temperature, and should be worked as little and at as low temperature as possible.

Aluminium-Bronze.—Aluminium is added to copper and to the bronzes and brasses with good results. The alloy, copper 90, aluminium 10, may be worked cold or hot like wrought iron, but not welded. Its tenacity is sometimes

nearly 100,000 pounds per square inch (7,030 kilos per square mm.), and its average is not far from three-fourths as great. It is hard and stiff and very homogeneous. Wire has been given a tenacity exceeding 125,000 pounds per square inch (8,776 kilos per square mm.). Its specific gravity is 7.7. In compression this alloy has been found capable of sustaining a little more than in tension (130,000 pounds per square inch, 9,139 kilos per square mm.), and its ductility and toughness were such that it did not even crack when distorted by this load. It is so ductile and malleable that it can be drawn down under the hammer to the fineness of a cambric needle. Measuring its stiffness, the Messrs. Simms found * that it had three times that of gun-bronze and 44 times that of brass. It works well, casts well, holds a fine surface under the tool, and when exposed to the weather; and it is, in every respect, considered the best bronze yet known. Its high cost alone prevents its extensive use in the arts.

The density of aluminium-bronze, has been determined by M. Riche,† with the following results:

BRONZE CONTAINING TEN PER CENT. OF ALUMINIUM.

	DENSITY.	
	I. WT. = 120^{gr}.568.	II. WT. = 120^{gr}.275.
After casting	7.705	7.704
After tempering	7.706	7.704
After annealing	7.706	7.705
After tempering	7.707	7.707
After annealing	7.703	7.704
After impact	7.703	7.702
After tempering	7.701	7.702
After impact	7.699	7.703

* Ure's Dict., Art. Aluminium.

† *Ann. de Chimie*, vol. xxx., 1873, pp. 351–419. Appendix.

BRONZE CONTAINING FIVE PER CENT. OF ALUMINIUM.

	DENSITY.	
	I. WT. = 129^{gr}. 575.	II. WT. = 129^{gr} .161.
After casting	8.252	8.262
After tempering	8.259	8.259
After annealing	8.255	8.262
After tempering	8.257	8.262
After annealing	8.257	8.262
After impact	8.264	8.264
After tempering	8.263	8.264
After impact	8.263	8.265

Tempering, annealing, and mechanical action produce no noticeable variation in the volume.

These alloys are very uniform in character and work regularly and smoothly.

Uses of Aluminium-Bronze.—Aluminium-bronze, composed of 9 parts copper and 1 part aluminium, was proposed in 1864 as a material for small coins, and with this object in view the assayer of the United States mint made a number of careful experiments with it. The assayer states that aluminium-bronze possesses much greater hardness than copper alone, but less malleability and ductility. When rolled into sheets, it requires annealing at every third passage through the rolls; when drawn into wire it must also be frequently annealed. To strike a coin of this bronze required unusual force. It tarnishes quite readily, but not more so than copper.

Aluminium-bronze containing 7½ per cent. of aluminium is greenish in color, according to Morin, while other compositions on either side are golden. Even 1 per cent. added to copper causes a considerable increase in ductility and fusibility, and enables it to be used satisfactorily in making castings. Two per cent. gives a mixture used for castings which are to be worked with a chisel. The standard aluminium-bronze—10 per cent. aluminium—is brittle after the first fusion, but becomes more ductile as well as stronger by repeated refusion. It makes good castings, is easily worked,

and may be forged at a red heat, and is fairly ductile under the hammer even when cold. It is softened by sudden cooling from a red heat. It takes a fine polish, is a half stronger than good wrought iron in tension, but has less strength in compression. Its coefficient of expansion is small at ordinary temperatures. Its liability to crack in large masses makes it difficult to get large castings. It has great elasticity when made into springs; it is found useful for watches, and has the decided advantage over steel of being but little liable to oxidation; the addition of 5 per cent. silver is advised to pure aluminium to make springs. Kettles of this alloy have been used in making fruit syrup and preserves.

The alloy of aluminium with 4 to 5 per cent. silver is used in making balances for chemists. The introduction of a very minute proportion of bismuth makes this metal very brittle.

Steel containing but 0.08 per cent. aluminium is said to be greatly improved by its presence.

An alloy of 2 or 3 copper and 97 or 98 aluminium is found useful in making ornamental silver-colored castings which are to be chased and engraved.

The alloys of aluminium and copper may be made by fusing together the oxides with metallic copper and enough carbon and flux to reduce them. The oxides, as well as the other materials, should be as finely divided as possible, and the carbon introduced in excess.

Copper and Nickel are quite easily alloyed, giving a metal of usually white color, hard, rather brittle, and quite easily oxidized. When the nickel forms 30 per cent. of the whole, the alloy is easily fused, strong, and tough, of a silvery-gray color, and slightly magnetic. White copper and German silver consist wholly or partly of this alloy.

Copper and nickel unite in a wide range of proportions. In color they range from the red of copper to the blue-white of nickel, according to their proportions. Adding nickel in the proportion of 0.10, the alloy is very ductile, light copper-red in color, and moderately strong; with 0.15 nickel, the color becomes very light red and the ductility is still great; 0.25 nickel gives an alloy nearly white; 0.30 nickel produces

a silver-white metal. Berthier's alloy, copper 0.682, nickel 0.318, is fusible, ductile, strong, bluish-white, slightly magnetic and somewhat crystalline near the surface.

"White copper," so-called, is such an alloy, usually containing slight quantities of iron and silicon.

Nickel coinage is now used by several nations; it was first privately coined by Feuchtwanger, of New York City, in 1837; Switzerland began using it in 1850, the United States in 1857, and Belgium in 1860. The U. S. coins now contain copper 75, nickel 25.

German Silver.—Copper, zinc, and nickel alloy readily. These compositions were used at a very early date in China, and have been known as packfong, tutenag, and white copper. The East Indian or Chinese tutenag is a grayish-white alloy, somewhat sonorous, and brittle. Its composition has been given as copper 44, zinc 40, nickel 16. The other alloys above named are nearly silver-white, malleable hot or cold, have a beautiful lustre, and very sonorous. The specific gravity is 8.5. Alloys of European manufacture, of similar characteristics, are now common. Viennese alloys have been found by Gersdorff to contain:—

Table utensils;	copper,	50;	zinc,	25;	nickel,	25.
Ornaments	"	55;	"	25;	"	20.
Sheet metal	"	60;	"	20;	"	20.

Frick's alloys contain copper, 50 to 55; zinc, 30 to 31; nickel, 17 to 19. These are white and hard but ductile, and have a specific gravity from 8.5 to 8.6; they are used in making table utensils and ornamental objects. The alloy, copper 56, zinc 5, and nickel 39, makes a fine white metal of the same class with the preceding.

German silver, as made by good makers, consists usually of

Copper	60
Zinc	20
Nickel	20
	100

Tin and lead in equal parts make an alloy used for organ pipes. It is cast in sheets on a table; these sheets are beaten smooth with a "planer," trimmed to size, rolled into shape and soldered together at the abutting edges.

Tin and Zinc unite, in all proportions, readily and uniformly, the quality varying less with variation of proportions than in alloys generally, as may be seen by studying the change of strength exhibited by the map and model shown in the chapter on the ternary alloys. The introduction of zinc increases the hardness of tin, and rather increases its whiteness, when in small proportion; in larger quantities it reduces ductility perceptibly. The alloy is of granular, sometimes crystalline, structure, as revealed by fracture, and is somewhat sonorous. With equal parts tin and zinc the alloy is rather hard, moderately ductile, and of a very brilliant lustre.

According to Koechl, the following are melting-points of these alloys:

FUSION OF TIN-ZINC ALLOYS.

TIN.	ZINC.	TEMPERATURE OF FUSION.		REMARKS.
		Deg. Fahr.	Deg. Cent.	
1	3	500–572	260–300	Pure metals.
2	4	572–662	300–350	" "
3	2	428–680	220–360	" "
1	1	472–662	250–350	Commercial.
1	1	680–932	460–500	Pure metals.

The alloy of equal parts of tin and zinc is said by some authorities to be nearly as strong as brass, to be much cheaper, and a better anti-friction metal; but it is necessary that the zinc should be very pure. This alloy has been used in the form of roofing sheets. The alloy tin 75, zinc 25, makes excellent metal patterns, the alloy flowing freely, running "sharp" and expanding slightly when solidifying; it should not be overheated, and should be constantly stirred while pouring,

to insure uniformity. This metal works easily, turns well in the lathe, and does not clog the file.

Antimony, Bismuth, and Lead unite to form an alloy which expands on cooling, and which is therefore used for type-metal. Mackensie's alloy is antimony 16, bismuth 16, lead 68. Stereotype plates of good quality may be made of this composition.

Antimony, Tin, and Lead are alloyed in the proportion of antimony 17, tin 13, lead 70, to form another Mackensie metal for stereotype plates and other printers' work. Sheets of this, or a similar alloy, are used in engraving music for printing; a composition reported by Berthier is antimony 5, tin 60, lead 35.

Antimony, Tin, and Zinc, in the proportions antimony 12, tin 44, zinc 44, make an alloy considered excellent for lining pump-barrels.

Antimony, Bismuth, Tin, and Lead, in the proportions tin 76, bismuth 8, antimony 8, lead 8, form the "Queen's Metal," which is one of the "pewter" alloys of greatest beauty and durability.

Pewter and Britannia Metal.—*Pewter* has a wide range of composition, from tin 20, copper 1, to tin 2, copper 1. The alloy is often mixed with lead, of which the Pewterers' Company in 1772* permitted enough to bring the density of the pewter from $\frac{1835}{1820}$ to $\frac{1985}{1820}$ that of tin. The best *Britannia*, a metal of this class, is said to be tin 77, antimony 15, copper 7, zinc 2; the alloy is cast in flat ingots and rolled into sheets.

Britannia wares, made in Sheffield, are often composed of 3½ parts block tin, 28 parts antimony, 8 of copper, and 8 of brass. The tin is melted and kept at a red heat while the antimony, the copper, and the brass are successively added, molten. The liquid alloy is ladled into the ingot moulds, which are slab-shaped cast-iron boxes, and the slabs thus made are subsequently rolled into sheets or recast into the form desired, or into such shapes as may be easily modified to the necessary extent. Spherical vessels are usually "spun up" in halves, which are then united by soldering. The

* British Industries. Bevan, 1871.

solder is any very fusible composition of this class, and is often made of tin 75, lead 25. The fusibility of the metal is such that it requires some dexterity and great care to prevent its injury in the process of soldering. Britannia is easily shaped by all the familiar processes; it may be cast, rolled and hammered, and cut in the lathe or by hand tools with equal facility.

Iron and Manganese have a strong affinity. In small proportions manganese confers whiteness upon iron, and the alloy called "ferro-manganese" is considerably used in making steels containing very little carbon; the carbide of this alloy, known as "spiegeleisen," or simply "spiegel" in the trade, is used in carburetting iron to produce steels "higher" in carbon.

A small proportion of manganese renders iron less fusible, and is said to increase its tenacity. Many of the ingot-irons in the market, called "mild" or "low" steels, contain more manganese than carbon and are very strong and ductile, and make excellent material for use where great changes of temperature are not met; this alloy is not considered suitable for springs, however. In large doses, manganese does not reduce the ductility and malleability of iron to the extent observed with the introduction of carbon. Karsten found that nearly 2 per cent. manganese improved iron. Mushet found that the alloy iron 71, manganese 29, was not magnetic, and concluded that the maximum attainable in iron was 40 per cent. manganese. As the percentage of manganese increases, the alloy becomes whiter, harder, more infusible, and more brittle if the manganese is present in considerable amount; it is more subject to oxidation also.

Platinum and Iridium alloy to form a composition, according to Matthey,* which is homogeneous and is capable of being forged. Its density is 21.5 when of the composition, platinum 98.5, iridium 12.5 by mixture, and platinum 90, iridium 10 by analysis. The density of the iridium was 22.38. The coefficient of expansion was from 0° to 16° C. (32° to 41° F.), 0.0000254.

* Proc. Royal Society, 1878.

Spence's "Metal" is not, strictly speaking, a metal, but is a compound obtained by dissolving metallic sulphides in molten sulphur,* which is found capable of receiving into solution nearly all known compounds of sulphur and the useful metals. It was discovered by J. B. Spence in the year 1879. The solution, on cooling, solidifies, forming a homogeneous, tenacious mass of the specific gravity 3.37 to 3.7 at 0° C. (32° F.). According to Dr. Hodgkinson, when finely powdered, it is acted upon slowly by concentrated HCl and NO_3HO in the cold; in large lumps, little or no action takes place; the expansion coefficient appears to be small. The fracture is not conchoidal, but somewhat like that of cast iron.

It is said to be exceedingly useful in the laboratory for making the air-tight connections between glass tubes by means of caoutchouc, and a water or mercury jacket, where rigidity is no disadvantage; the fusing point is so low that it may be run into the outer tube on to the caoutchouc, which it grips on cooling, like a vice, and makes it perfectly tight. It melts at 320° F. (160° C.), expands on cooling, is claimed to be capable of resisting well the disintegrating action of the atmosphere, is attacked by but few acids and by them but slowly, or by alkalies, and is insoluble in water, and may receive a high polish; it makes clear, full castings, taking very perfect impressions; it is cheap and easily worked. It has been used as a solder for gas-pipes, and as a joint-material in place of lead.

* Jour. Society of Arts. London, 1879.

CHAPTER XI.

MANUFACTURE AND WORKING OF ALLOYS.

Alloys of General Application; Brass Working.—Of the alloys described in the preceding chapter but a few are employed by the engineer in his professional work, and still fewer are familiar and in common use. Of all the known alloys, the bronzes and the brasses, the coin alloys and a few compounds of tin, lead, zinc, antimony and bismuth, only, are so well known as to be properly classed among the materials of constructive engineering. All the others are of use only in a restricted range of application and for a few special purposes.

The methods of preparation are practically the same for all, and the "brass foundry" is usually resorted to in making them all.

Brass work is divided into several branches, which, according to Aitken, are:

1. Brass casting, or ordinary foundry work;
2. Bell and cabinet-ware casting;
3. Pot-metal and plumbing work;
4. Stamped brass-work;
5. Rolled brass; wire-work; sheathing;
6. Tube making;
7. Lamp making;
8. Gas fitting;
9. Naval brass-founding.

Several of these lines of work may often be carried on together, but it is usual to combine those most nearly related—as those involving casting, those in which the metal is rolled or wire-drawn, stamping, tube-making and brass finishing.

Casting is described at length in pp. 317–319, on the brass foundry.

Sheet-rolling is a very important branch of brass-making, employing a large number of work-people and sustaining a host of minor trades.

The ingot brass for sheet-brass rolling is cast in broad, shallow, iron ingot-moulds, or when larger masses are to be used, in stone moulds, cut out of the solid block. They are well oiled and powdered with charcoal before filling them.

The cast ingots of brass are called "strips," and are rolled, cold, by several successive "passes" through heavy rolls, with occasional annealing as they become hardened by the operation of the rolling-mill. When the surface of the sheet is found to be irregular and to contain spots of impurity, the hand-scraper, or a scraping machine, is employed to remove them, and thus to prevent liability to cracking and raggedness of surface or edges. When rolled nearly to gauge, the sheet is "pickled," to remove the oxidized surface, and is then passed through the finishing rolls, which are finely polished and give the sheet its final finish. Muntz metals can be rolled hot, and therefore much more cheaply than other brass.

Wire-drawing is conducted as in the drawing of iron and steel wire; but the rods to be drawn are cut, by a slitting-mill, from sheet-brass. Like iron wire, brass must be occasionally annealed, in passing from wire-block to wire-block.

Stamping in dies can be practised with any of the soft and ductile brasses, or other alloys. It is by this process that a large proportion of the cheap brass ornaments are made, as well as many parts of various utensils, as lamps, door-fixtures and kitchen utensils. The die on the anvil is made of the desired form, and the metal is "struck" into it by the blow of a "drop-hammer" carrying a companion die, the drop falling from one to five feet according to weight and power. Heavy drops are always worked by steam power. The "force," or die carried by the drop, is usually of soft metal; the die on the anvil is of steel. For fine and small intricate work, several blows are struck. This kind of work

does not compare favorably with cast brass, or bronze, in clearness and fineness of lines.

Brass Tubes are made by either of several methods. Sheet-brass is rolled, over a form, into a tube, and the edges soldered together, or they are rolled into cylindrical shape and soldered. For exact sizing, a mandrel is placed within the tube and on this it is rolled to gauge. Seamless tubes, such as are used in steam boilers and elsewhere under pressure, are made by rolling, or by drawing down cast cylinders in a mill consisting of several sets of steel rolls.

Brass-finishing includes lacquering, bronzing, dipping and burnishing and other methods of giving a surface finish, described at the end of this chapter.

The Brass Foundry is usually an adjunct to large manufacturing establishments. It is generally small, and the moulding room and casting room are in one. A drying room, or core-oven, is conveniently located at the moulding room side; it may be heated by either steam or by stoves, the former being the better plan. A cleaning room and, beyond it, a finishing or dressing room, should be attached to the foundry, and, for fine work, a lacquering room is also required.

The "patterns" are of wood or iron, as in iron founding, or they may be of stucco and pipe-clay. Patterns for brass castings must be larger than for iron, as shrinkage is one-half greater, *i.e.*, $\frac{3}{16}$th inch to the foot, or about 20 cm. per metre. The "shrink-rule" used for iron will not apply for brass-work. The flasks, and all details of apparatus, tools, and work are very similar to those used in an iron foundry, and the methods are the same in the main. Castings are cooled rapidly, often with water, to soften and toughen them.

Melting and Casting.—In the melting of the materials in the making of alloys in the foundry, two general methods of procedure are practised; in the one, all the constituents are fused at the same time in the same crucible or melting pot; in the other they are fused one after another in a definite order, which is determined by their relative fusibility, volatility, and liability to oxidation, or to absorb oxygen and other gases. The first of these methods is, perhaps, the most

common, but the second is by far the better; thus in making the most common ternary alloys, those of copper, tin, and zinc, the copper is best melted first, the tin should be next introduced, and the zinc, which is volatile and oxidizable, is added last. If lead is to be introduced into such an alloy, it is found best to put it into the crucible last.

Other things being equal, the metals should be added in the order of their non-volatility; the next controlling quality is infusibility; the least fusible should generally be melted first.

The casting and cooling of the alloy is hardly less a matter of importance than the methods of fusion. Liquation is very liable to occur in certain cases, as in many alloys of copper with tin, and to prevent it the most prompt cooling possible is resorted to; the use of "chills," or metal moulds, is sometimes found essential to success. In these cases, it is not advisable to pour the alloy "cold," as liquation may have already commenced; they should be poured hot—"sharp," as the term is often used in the foundry—and yet compelled to chill quickly, if possible.

The apparatus of the foundry, in which alloys are mixed and cast, consists of an air, or wind, furnace, sufficiently large to receive the crucibles in which the metals are melted, or, sometimes, when the masses handled are very large, a reverberatory "open hearth" furnace, which is preferably heated with gas or liquid fuel; of a collection of crucibles, which may be iron melting-pots for lead and alloys which melt at a low heat and have no affinity for iron, but which are usually of clay, of graphite, or of graphite mixed with clay; and utensils for weighing and handling the metals, fuels, and crucibles. In some cases platinum and silver crucibles are used, as in laboratory work, but these are rarely needed. The crucibles should be carefully selected, since the cost of these vessels is often an important item of the expense account.

In melting, the constituents of the charge being introduced in the order decided to be, on the whole, best, the liquid metal should be carefully stirred after each addition, and in such a manner as to secure most complete intermixture without liability to injure it by exposure to an oxidizing

atmosphere. When the alloy is not homogeneous and sound, it may sometimes be greatly improved by refusion. In making large castings, the several metals to be alloyed are usually melted separately and all finally poured together into a reservoir in which they are thoroughly mixed before "pouring the casting." Where a reverberatory furnace is used, the process may be conducted as in crucibles; in this case, especial precautions must be observed to preserve a deoxidizing flame within the furnace. When they are used in making bronzes, great care is taken to keep the mass constantly stirred to prevent liquation and the floating of the tin to the top.

The fuel used in the mint-furnace is generally coke, which should be dense, hard, bright, and should ring when struck.

In large establishments, and especially in melting bronzes, the open-hearth reverberatory is very generally used. Bell founders use a peculiar dome-topped furnace, melting at more moderate heat.

In "pouring," the small castings are made first and the heavier are poured with the cooler metal.

Sheet-brass is first cast in plates between heavy marble blocks washed with loam and well dried, or, often in ingots. They are rolled in heavy plate-mills and occasionally annealed as they become hard and unmalleable in the rolls.

In making brass-plates and sheet-brass, the surface is pickled, after the sheet is reduced nearly to size, in order to give it a clean surface, and then, when a finish is demanded, it is given by a set of polished rolls.

Wire-brass is cast and rolled into plates, which are cut into narrow strips in a "slitting-mill" by narrow interlocking roll-collars. These strips are rolled to a conveniently small size, and are then sent to the wire-mill to be finished in the draw-plates.

Furnace Manipulation.—In filling the furnaces, the crucibles are slowly heated to avoid danger of breaking; they are at first set bottom upward. When well heated, they are set mouth upward and charged with the broken copper. The tin or zinc is heated at the mouth of the furnace and is added gradually to the copper as the latter becomes fluid.

The zinc is liable to volatilization, and is, therefore, when introduced, plunged well below the surface of the molten copper. The Author has sometimes had it wrapped in dry paper or other protecting material to secure protection from loss by volatilization and oxidation. Great care is needed to prevent the introduction of cold and especially of damp metal; seriously dangerous explosions are sure to take place if this should happen.

The fumes arising from the molten alloys when poured are unhealthy, and a form of intermittent fever known as the "brass ague" is often produced by them where proper precautions in handling and in securing ventilation are not observed.

The brass-founder's furnace consists of a vertical cast-iron cylinder or other casing—often a brick structure—lined with fire-brick to a diameter of 10 to 15 inches. The flue is led off at one side at the top, and the whole is covered with a plate having an opening of sufficient size to permit the crucible to enter and fitted with a cover plate. The grate is usually composed of loose bars which can be easily and independently withdrawn or inserted.

Each furnace contains one crucible, and large castings are only made where several furnaces are in use or where the alloy can be melted in a reverberatory furnace. Tuyeres are sometimes fitted for the purpose of increasing the rapidity of melting, and the crucibles are then, when large castings are to be made, emptied as fast as ready into a ladle which serves as a collecting reservoir from which the mould is filled.

The fuel is usually either coke or charcoal.

The Preparation of the Alloys involves considerable knowledge of the behavior of the mixture and its constituents while fusing and while the alloy is being formed, and can only be successful when the skill and judgment of an experienced founder aid in the work of melting and casting. There are two methods of making alloys: the one is that of weighing out the constituents in proper proportions and mixing and melting all together; the other is that of mixing and melting the constituents successively and in an order

dependent upon the character of the metals and the alloy made of them. The first is the usual method and is the least troublesome and expensive; but it does not usually give as sound, uniform, and strong castings of the alloy as the second. In the latter case, the metal of highest melting point is usually first fused and the others are added in the order of fusibility or volatility. The order of introduction into the crucible or melting-pot has an appreciable effect on the quality of the alloy.

After the alloy has been made and poured into the ingot, or other mould, it may change in composition by the process of separation or "liquation," to which reference is elsewhere made, either by the denser metal settling out or by the change due to formation of other definite alloys of greater stability at various points in the mass, thus altering the composition of the metal all around those points. Thus in gun-metal (bronze) the surface of fracture often has a variegated color due to separation of the tin and the production of a variable composition of alloy. This will be noted in the description of the behavior of many alloys made by the Author. It will be seen that the rapid cooling secured by the use of metal moulds is the best means of preventing this liquation. Slow cooling, affording ample time for the separation and reconcentration of the constituents, and for the production of crystals, permits, often, very serious loss of quality. It will be noted that the best alloys are usually made most successfully when the molten metal is poured "sharp," *i. e.*, hot, and then rapidly cooled to the point of solidification.

The process of liquation is sometimes usefully applied, as in the Pattinson process of separating the metals in argentiferous galena, or in cupriferous ores of lead.

The desired alloy is very rarely made of its essential constituents only. A simple binary alloy of copper and tin is, for example, rarely made in commercial work. Lead is often added to give color, zinc to cheapen it or to flux it, and sometimes other metals to give special qualities. Statuary bronze usually contains some lead and zinc to give it its peculiar "patina"; bronze used in "hardware" and architectural

work, in bearings, etc., contains lead to give color and to make it wear well; brass is hardened greatly, and strengthened, by the addition of one per cent. tin, or more, as in the "maximum alloys" discovered by the Author. In such cases, the metal is added in small quantity to the mixture, after the latter is in fusion and alloyed.

Minute Quantities of Alloy often greatly influence the properties and quality of metals. Thus, it is stated * that lead alloyed with 0.003 per cent. of antimony turns perceptibly freer than pure lead; that an addition of 0.007 per cent. copper unfit leads for use in the manufacture of white lead; that gold containing 0.05 per cent. of lead exhibits greatly decreased ductility; that copper containing 0.5 per cent. iron has but 40 per cent. of the conductivity of pure copper.

Nickel is too brittle to work; but, alloyed with 0.1 per cent. magnesium or 0.3 per cent. phosphorus, it can be rolled and worked. Brittle steel is sometimes made tough and malleable by alloying it with 0.08 per cent. manganese or magnesium. A difference of 0.001 per cent. in the amount of phosphorus present in the best Swedish irons can be plainly observed by a change of malleability.

Art Castings in Bronze represent the most perfect work known in the department of foundry work. It has been practised from the earliest known and even pre-historic periods, and the analyses of art castings found in the Egyptian tombs and in Nineveh prove that the composition then adopted was substantially that of the statuary bronze, and that of the art-work of to-day. The Greeks began to make bronzes several hundred years before the Christian era, and before the commencement of that era, had attained great skill in the art. The statue of Apollo, at Rhodes, made by the pupil of Lysippus, Chares, 330 B.C., was about 100 feet (30 metres) high, and after having been shaken down by an earthquake some 60 years later, lay over 900 years prostrate, and was then carried away by a Jew who purchased it from the Saracens, making a load, as it is said, for 900 camels. The Chinese and Japanese first made use of bronze at some

* *Der Techniker*, 1883.

unknown but very early date. The art was long lost in Europe, but was revived in the 16th and 17th centuries, and now constitutes an exceedingly important industry.

Art castings of large size are moulded and cast precisely as other brass-founding is done; but great precaution is taken in the selection of materials, in determining exactly the desired proportions and in all the details of foundry practice and manipulation. The usual mixtures are given elsewhere.

In making statuary, the model is first formed, and is then lined off by the founder in sections in such manner that each will be likely to be easily moulded and will "draw" readily; plaster patterns are made of these sections separately, which are used in obtaining metal copies, which latter are finally joined together. Where the piece is to be cast whole also, the mould must be often made in many parts, in order that every section of the mould may be readily removed. In some cases, an elastic mould is made within which a wax model is formed, the latter being moulded in the sand in the usual manner. For such work, a plaster cast is usually first made, which is coated with any oily or glutinous substance which will not allow moisture to be transferred, and will not permit the adherence of the cope or mould, to be formed over it. By covering the model with a thin coating of wax, an outer mould can be constructed, and the inner and outer shapes may thus be separated by a thin space which represents that to be filled by the molten bronze, and determines the thickness of the casting. This space is often filled with wax and the latter is melted out when the mould is sent into the drying room or oven. Properly made, the mould has smooth, perfect surfaces of the exact form to be reproduced, and the bronze, when removed from it, is an exact reproduction of the model, only requiring a small amount of work to make it marketable. If the composition and the work are what is desired, the surface of the casting is smooth, precise in form, sharp in outline, and of good color. Statues thus made acquire, with age, a color or "patina" which distinguishes all good bronzes.

Statuary bronze, and bronze for art-work generally, should have, when newly cast, a fresh, yellow-red color, and a fine

grain, should be easy to work with file or chisel, very fluid when melted, taking the finest impressions of the mould, and when exposed to the atmosphere in the finished casting, should take the peculiar green patina characteristic of old bronze statuary of good quality. These qualities are not usually obtained in so high a degree in the copper-tin or copper-zinc alloys, the common bronzes and brasses, as in alloys containing the three metals. According to Guettier, the best of these alloys are:

COPPER.	ZINC.	TIN.
92	6	2
85	11	5
65	32	3

It is very usual to add 1 or 2 per cent. of lead; ancient bronzes contain as much as 6 per cent. According to Pliny, bronze was made by melting copper first, then adding 12½ per cent. of an alloy of equal parts tin and lead, known as *plumbum argentarium.*

Stereotype Metal, of which a good quality is made of 16 parts antimony, 17 parts tin, and 67 parts lead, is worked thus:

The type is brushed over with a small quantity of black-lead and oil, placed in a casting-frame, and a cast taken in plaster of Paris. This cast is dried in a hot drying-oven until absolutely free from all moisture, and is held in form, meantime, by securing it to a flat cast-iron plate. The stereotype metal is cast upon the matrix thus produced, and the plate thus obtained is planed up to a gauge and fitted to the press, or mounted on wooden blocks of the right height to work in the press. Damaged type are cut out and replaced with perfect ones.

A later process is the following:* A sheet of tissue paper covered with printing paper is placed upon a perfectly smooth metal plate, and the two sheets are pasted together.

These sheets are laid over the type, beaten into their interstices, covered with other sheets similarly beaten down, and

* Spon.

this process is continued until the mass of paper forms a matrix of satisfactory thickness and strength. Heavier paper, as cartridge paper, is used for the last layers. This matrix is dried carefully between surfaces which hold it in shape, is then brushed over with French chalk or black lead, and laid in the casting box, where the stereotype metal is cast over it and a plate thus made.

German Silver is made by English founders of small bells and similar articles of copper 57, zinc 19, nickel 19, lead 3, tin-plate 2. The copper and nickel are fused together first, the zinc added after their fusion, and the other metals last. Commercial zinc containing lead is rarely pure enough for the finer grades of this alloy which do not permit the introduction of lead. It is difficult to obtain this alloy in correct proportions and of good quality.

Babbitt's "Anti-attrition" Metal is usually not cast directly into the "brasses" to be lined with it. It is made by melting separately 4 parts copper, 12 Banca tin, 8 regulus of antimony, and adding 12 parts tin after fusion. The antimony is added to the first portion of tin, and the copper is introduced after taking the melting-pot away from the fire, and before pouring into the mould.

The charge is kept from oxidation by a surface coating of powdered charcoal. The "lining metal" consists of this "hardening," fused with twice its weight of tin, thus making 3.7 parts copper, 7.4 parts antimony and 88.9 parts tin.

The bearing to be lined is cast with a shallow recess to receive the Babbitt metal. The portion to be tinned is washed with alcohol and powdered with sal ammoniac, and those surfaces which are not to receive the lining metal are to be covered with a clay wash. It is then warmed sufficiently to volatilize a part of the sal ammoniac, and tinned. The lining is next cast in between a former—which takes the place of the journal—and the bearing.

Founders often prefer to melt the copper first in a plumbago crucible, then to dry the zinc carefully and immerse the whole in the barely fluid copper.

A report of a committee of the American Master

Mechanics' Association, reporting on the use of Babbitt metal, state that thirty-five replies to their circular gave the following facts relating to the use of Babbitt metal: Four use gibs with Babbitt; four use the solid octagon brass without Babbitt; seven use octagon with Babbitt; seven use half-round solid brasses without Babbitt; four use half round brasses in three pieces with Babbitt, and one makes no report of the use of Babbitt. All, with one exception, report that the Babbitt metal should extend the entire length of the journal and should be put on in strips ¾ to 1½ inches wide, at a point between the top and the front and back points of the journal bearing; one inserts it by drilling holes in the brass and then filling in with the metal. The Committee have observed that, in engines of from thirty-two to thirty-five tons weight, the half-round brass does not give as good results as in lighter engines. Good results may be obtained from a hexagon-shaped brass if properly fitted. The Babbitt metal will wear until it is cut through into the cast-iron. The recess in the top of the brass is of advantage also as a reservoir for oil; and as there is less bearing at that point, the brass wears away and the shaft beds itself into the brass, so that there is no lost motion or pounding between the shaft and the brass. The Committee is of opinion that the use of Babbitt metal is advisable.

Solders are alloys used in joining metallic surfaces, and parts of apparatus or constructions, by fusing them upon the surfaces of contact, and allowing them to cool, obtaining a more or less firm and tenacious union. They have a wide range of composition; the "soft solders" are made of tin and lead; "hard solders" are usually made of brass; and special solders are composed of various alloys of copper, zinc, lead, tin, bismuth, gold and silver. Haswell's table of solders is given later.

In soldering copper, brass, or iron with soft solder, a "soldering iron" is used to melt, and to apply the solder to the work. This instrument consists of a copper head, shaped somewhat like a machinist's hammer, the large end of which is inserted longitudinally in the claw-shaped end of an iron

holder, which is itself carried by a wooden handle; it is heated in a small charcoal-furnace, or "brazier," which is especially constructed for the purpose.

A "soldering fluid," usually a solution of zinc in hydrochloric acid, is used to remove the oxide from the surfaces to be joined and to give them a coating of zinc, to which the solder will promptly adhere.

Soldering is often successfully performed by cleaning the surfaces thoroughly, fitting them nicely together with a file, if necessary, placing a piece of tin-foil between them, binding them firmly together with "binding wire," and heating in the flame of a lamp or a Bunsen burner, or in the fire, until the tin melts and unites with both surfaces. Joints carefully made may be united, in this way, so neatly as to be invisible. When using the more fusible solders, as those containing bismuth, a fire is seldom needed. When one joint has been made with hard solder, it is not always safe to make another near it with the same composition; a softer solder should then be used.

Soft solders are not malleable, and where this quality is demanded, the solder is necessarily of the hard variety. An excellent solder for such work is made with silver and brass in equal parts.

Coin silver, in thin sheets, is an excellent solder for copper, hard brass, and wrought iron. Cast iron cannot be readily soldered, and the attempt is rarely made.

In making solders, great care is to be taken to secure uniformity of composition; they are often granulated by pouring from the crucible or ladle through a wet broom or from a considerable height into water, or they are cast in ingots and reduced to a powder by filing or by machinery. The silver and the gold solders are usually rolled into sheets; the soft solders are generally sold in sticks, as is also pure tin; those which are rich in tin are distinguished by their peculiar "tin-cry," which is destroyed by a very small admixture of other metals. In making solders, as all other such alloys, the most infusible metal is first melted, and the other constituents are added in the order of infusibility. Soft solders are very

fusible and are melted under tallow, and the hard solders are prepared under a covering of powdered charcoal to prevent oxidation.

Yellow brass, containing from 65 to 80 per cent. copper, will be found useful at times in brazing wrought iron, mild steel, and all the common brasses and bronzes containing less than 10 per cent. tin or lead. Equal parts of copper and zinc make a good solder for yellow brass and is known as "broom" solder. Tin and lead are sometimes added, but probably without advantage, the one making the solder hard, the other weakening it. For brazing iron, yellow brass is excellent.

In using these solders, the surfaces to be brazed should be well cleansed, sprinkled with borax, and bound tightly together with fine iron wire. A clay "dam" around the joint is useful in confining the solder in place when melting. The heating should be gradual and the temperature brought slowly up to a red heat, occasionally adding borax, and, finally, the heat should be more quickly raised until the solder melts and fumes, when the piece is cooled.

Silver and yellow brass make good solders for steel, melting at a moderately high heat and having considerable strength. Both solder and flux should be used sparingly to secure good work. Cast iron and alloys containing either tin or lead in considerable quantities cannot be easily soldered.

The soldering fluid answers as a flux for soft solders; borax is used with the hard varieties, as it dissolves the oxides of all metals thus treated, and leaves the clean metallic surface which is essential to perfect union. Sal ammoniac is often added to the soldering fluid when soft solders are used, and resin is a common, and in some respects the best, flux for tinner's work.

Platinum is soldered with gold, and German silver with a solder of equal parts of silver, brass, and zinc.

The essentials of a good solder are that it shall have an affinity for the metals to be united, should melt at a considerably lower temperature, should be strong, tough, uniform in composition, and not readily oxidized.

Standard Compositions are often adopted by en-

gineers for the various purposes to which they apply the alloys. The tables hereafter presented are full of examples. In further illustration, we have the following as the compositions adopted by the Paris, Lyons, and Mediterranean Railway of France:

STANDARD ALLOYS.

ALLOY.	PROPORTIONS.					USES.
	Copper.	Tin.	Zinc.	Lead.	Ant.	
Gun-metal, 1.	82	16	2	..	..	Bearings.
" 2.	84	14	2	..	..	Valves, Screws, etc.
" 3.	90	8	2	..	..	Cocks, Whistles, etc.
Brass, 1.	70	..	30	..	..	Tubes.
" 2.	67	..	33	..	..	Stuffing-boxes, etc.
" 3.	65	..	35	..	..	Handles, Latches.
" 4.	63	..	37	..	..	Plates, Washers.
White metal.	5	71	..	..	24	Bearings.
Packing "	..	14	..	76	10	Stuffing-boxes.
Solder.	..	45	..	55	..	For tin plate.
"	..	40	..	60	..	" zinc "

The useful alloys are, as already seen, exceedingly numerous, and are of extraordinary variety in appearance and physical qualities. They are applied to an almost equally wide range of uses. The following very complete lists will give an idea of their number, quality and applications.*

* Chas. Haswell; Pocket-book, 1882. C. Bischoff: Das Kupfer und seine Legirungen; Berlin, 1865. P. A. Bolley: Recherches Chimiques; Paris, 1869. A. Herve: Alliages Métalliques, Manuel-Roret; Paris, N.D.

ALLOYS AND COMPOSITIONS.—HASWELL.

	COPPER.	ZINC.	TIN.	NICKEL.	LEAD.	ANTIMONY.	BISMUTH.	SILVER.	COBALT OF IRON.	IRON.	ARSENIC.
Argentan	55.	24.	....	21.	....	....	....	....	....	....	....
Argentiferous alloy	50.	2.5	2.5	40.	2.5	....	....	....	....	2.5	....
Babbitt's metal	3.7	....	89.	....	....	7.3	....	....	....	....	....
Brass, common	84.3	5.2	10.5	....	....	....	....	....	....	....	....
" "	75.	25.	....	....	....	....	....	....	....	....	....
" " hard	79.3	6.4	14.3	....	....	....	....	....	....	....	....
" mathematical instruments	92.2	....	7.8	....	....	....	....	....	....	....	....
" Pinchbeck	80.	20.	....	....	....	....	....	....	....	....	....
" red tombac	88.8	11.2	....	....	....	....	....	....	....	....	....
" rolled	74.3	22.3	3.4	....	....	....	....	....	....	....	....
" tutenag	50.	31.	....	19.	....	....	....	....	....	....	....
" very tenacious	88.9	2.8	8.3	....	....	....	....	....	....	....	....
" wheels, valves	90.	....	10.	..	....	....	....	....	....	....	....
" white	10.	80.	10.	....	....	....	....	....	....	....	....
" wire	67.	33.	....	....	....	....	....	....	....	....	....
" yellow, fine	66.	34.	....	....	....	....	....	....	....	....	....
Britannia metal	....	....	25.	....	....	25.	....	....	....	....	....
" when fused add	....	....	....	....	....	25.	25.	....	....	....	....
Bronze, red	87.	13.	....	....	....	....	....	....	....	....	....
" red	86.	11.1	2.9	....	....	....	....	....	....	....	....
" yellow	67.2	31.2	1.6	....	....	....	....	....	....	....	....
" cymbals	80.	....	20.	....	....	....	....	....	....	....	....
" gun metal, large	90.	....	10.	....	....	....	....	....	....	....	....
" " small	93.	....	7.	....	....	....	....	....	....	....	....
" metals	93.	....	7.	....	....	....	....	....	....	....	....
" statuary	91.4	5.5	1.4	....	1.7	....	....	....	....	....	....
Chinese silver	65.1	19.3	....	13.	....	....	....	2.48	12.	....	....
Chinese white copper	40.4	25.4	2.6	31.6	....	....	....	....	....	....	....
Church bells	80.	5.6	10.1	....	4.3	....	....	....	....	....	....
"	69.	....	31.	....	....	....	....	....	....	....	....
Clock bells	72.	....	26.5	....	....	....	....	....	....	1.5	....
Clocks, musical bells	87.5	....	12.5	....	....	....	....	....	....	....	....
German silver	33.3	33.4	....	33.3	....	....	....	....	....	....	....
"	40.4	25.4	....	31.6	....	....	....	....	....	2.6	....
" fine	49.5	24.	....	24.	....	....	....	....	....	2.5	....
Gongs	81.6	....	18.4	....	....	....	....	....	....	....	....
House bells	77.	....	23.	....	....	....	....	....	....	....	....
Lathe bushes	80.	....	20.	....	....	....	....	....	....	....	....
Machinery bearings	87.5	....	12.5	....	....	....	....	....	....	....	....
" hard	77.4	7.	15.6	....	....	....	....	....	....	....	....
Metal that expands in cooling	....	....	....	...	75.	16.7	8.3	....	....	....	....
Muntz metal	60.	40.	....	....	....	....	....	....	....	....	....
Pewter, best	....	....	86.	....	....	14.	....	....	....	....	....
"	....	....	80.	....	20.	....	....	....	....	....	....
Printing characters	....	....	....	....	80.	20.	....	....	....	....	....
Sheathing metal	55.	45.	....	....	....	....	....	....	....	....	....
Speculum "	66.	....	22.	....	....	....	....	....	....	....	12.
" "	50.	21.	29.	....	....	....	....	....	....	....	....
Telescopic mirrors	66.6	....	33.4	....	....	....	....	....	....	....	....
Temper *	33.4	....	66.6	....	....	....	....	....	....	....	....
Type and stereotype plates	....	....	....	....	69.	15.5	15.5	....	....	....	....
White metal	7.4	7.4	28.4	....	....	56.8	....	....	....	....	....
" hard	69.8	25.8	4.4	....	....	....	....	....	....	....	....
Oreide	73.	12.3	{ Magnesia..... 4.4 Sal-ammoniac 2.5			Cream of tartar 6.5 Quicklime.....1.3					

* For adding small quantities of copper.

SOLDERS.

	COPPER.	TIN.	LEAD.	ZINC.	SILVER.	BISMUTH.	GOLD.	CALCIMINE.	ANTIMONY.
Tin	..	25	75	..	..	..	..	..	..
"	..	58	16	..	..	16	..	..	10
" coarse, melts at 500°	..	33	67	..	..	..	..	..	..
" ordinary, melts at 360°	..	67	33	..	..	..	..	..	..
Spelter, soft	50	..	..	50	..	..	..	..	..
" hard	67	..	..	33	..	..	..	..	..
Lead	..	33	67	..	..	..	..	..	..
Steel	13	..	..	5	82	..	..	..	..
Brass or copper	50	..	..	50	..	..	..	..	..
Fine brass	47	..	..	47	6	..	..	..	..
Pewterers' or soft	..	23	45	..	..	22	..	..	..
" "	..	50	25	..	..	25	..	..	..
Gold	4	..	..	..	7	..	89	..	..
" hard	66	..	..	34	..	..	..	..	..
" soft	..	66	34	..	80	..	..	..	..
Silver, hard	20	..	..	..	67	..	..	21	..
" soft	12	..	..	..	..	..	..	..	..
Pewter	..	40	20	..	..	40	..	..	..
Iron	66	..	..	33	..	..	..	..	1
Copper	53	47	..	..	..	..	..	.	..

FUSIBLE COMPOUNDS.

COMPOUNDS.	ZINC.	TIN.	LEAD.	BISMUTH.	CADMIUM.
Rose's, fusing at 200°	....	25	25	50	..
Fusing at less than 200°	33·3	..	33·3	33·4	..
Newton's fusing at less than 212°	....	19	31	50	..
Fusing at 150° to 160°	....	12	25	50	13

Special Recipes.—The best bronze compositions for use in engineering are, according to Guettier,* the following:

For pumps, bolts and similar pieces:

Copper	88	Copper	90
Tin	12	Tin	10
	100		100

The latter is the softer of the two. Often from one to four per cent. of zinc is added, as already stated.

* Guide Pratique ; Paris, 1865.

For eccentric-straps and connecting-rod bearings:

Copper.....	83	84	83	84	82	85.25
Tin.....	15	14	15	14	16	12.75
Zinc.....	2	2	1.5	1.5	2	2
Lead.....	..	..	0.5	0.5	..	.....
	100	100	100.0	100.0	100	100.00

The addition of lead and increase of copper gives softer alloys. Lead is often used more freely than above.

Locomotive driving-axle bearings:

Copper.....	74	80	85.25	86	89
Tin.....	9.5	18	12.75	14	8
Zinc.....	9.5	2	2.00	..	3
Lead.....	7	..	....	..	..
	100.0	100	100.00	100	100

The Author prefers gun-bronze to either of the above.

For Locomotive Slide Valves—

Copper phosphate.....	3.50
Copper.....	77.85
Tin.....	11.00
Zinc.....	7.65
	100.00

Connecting-Rod Brasses—

Copper phosphate.....	3.5
Copper.....	74.5
Tin.....	11.0
Zinc.....	11.0
	100.0

Axle-boxes—

	No. 1.	No. 2.
Copper phosphate.....	2.5	1.5
Copper.....	72.5	73.5
Tin.....	8.0	8.0
Zinc.....	17.0	19.0
	100.0	100.0

Parts demanding greater strength—

Copper phosphate	3.5
Copper	85.5
Tin	8.0
Zinc	3.0
	100.0

Zinc is here added to the bronze to aid in securing that homogeneousness which is essentially the result of the addition of phosphorus.

For pistons (rarely needed): copper, 89.75; tin, 2.25; zinc, 8.

For car and locomotive axle bearings:

Copper	80	79	86	89
Tin	18	18	14	2.5
Zinc	2	2.5	..	8.5
Lead	..	0.5	..	...
	100	100.0	100	100.0

For ordinary stationary machine journal-bearings: copper, 82; tin, 18.

For whistles of locomotives and bells:

Copper	80	81	78	79	78		71
Tin	18	17	20	23	22		26
Antimony	2	2	2	Zinc 6	..	Zinc	1.8
						Iron	1.2
	100	100	100	100	100		100.0

The last is the alloy of the famous "silver-bell" of Rouen.

For pump-buckets, valves and cocks:

Copper	88	88	86.8
Tin	10	10	12.4
Zinc	1.75	2	0.8
Lead	0.25	..	..
	100.00	100	100.0

For hammers (for use on finished work): copper, 98; tin, 2. This alloy will forge like copper; it may be hardened by adding more tin.

For wagon axle bearings:

Copper	78	Copper	25
Tin	20	Cast-iron	70
Zinc	2	Tin	5
	100		100

The best brasses may be taken, for general purposes, as accepted by good makers, as follows:

For turned work:

Copper	61.6	66.5	74.5	79.5
Zinc	35.3	33.0	25 0	20
Tin	0.5	0.5	0.5	0.5
Lead	2 5	....	....	....
	100.0	100.0	100.0	100.0

The richer colors are given by the higher proportions of copper. The official recipe for work in French dock-yards is:

Copper	65.80	76.0	85
Zinc	31.80	24.0	15
Tin	0.25	....	..
Lead	2.60	0.5	1
	100.45	100.5	101

The hardest compositions are used for the smallest pieces. These are used in the ornamentation of engines, for brass straps, for hinges, and for pulley-sheaves.

Cheap alloys for bearings have been made of the following wide range of composition:

Copper	56	5.5	58
Tin	28	19.5	28
Zinc	16	80.0	14
	100	100.0	100

The first—Fenton's alloy—is said to wear well, not to be specially liable to heating, and to be very durable. The last—Margraff's alloy—is of similar quality. The second composition is much cheaper and lighter, and takes the place of the white alloys used in bearings.

Kingston's metal, formerly much used for bearings, is made by melting 9 parts copper with 24 parts tin, remelting, and adding 108 parts tin, and finally 9 parts of mercury.

An alloy of 90 per cent. tin, 8 per cent. antimony, and 2 per cent. copper has been found excellent for crank and connecting-rod bearings on the Moscow and Nishni Railroad of Russia. On the Kursk-Charcow-Asow Railroad an alloy of 78.5 per cent. tin, 11.5 antimony, and 10 copper is considered very superior for pivots of all kinds, slide valves, eccentrics, stuffing-boxes, etc. The Swiss Nordöstbahn Company, in ordering locomotives recently, required the following preparation as a composition for axle journals: 10 parts of antimony added to 10 parts of melted copper, with 80 parts of tin added, and the alloy run into bars, to be remelted for use.

Bronzing is the process of staining or otherwise coloring the surface of brass, in imitation of bronze—usually imitating old bronze. The methods of bronzing and the bronzing liquids are different for different purposes and as practised in different localities and different trades. Brass is very seriously subject to oxidation, and when polished soon loses its brightness and its color. Polished surfaces are often protected by the process of lacquering (to be presently described), but the permanent preservation of the polish is rarely possible and a coloring or bronzing is very commonly resorted to. It was formerly customary to give scientific apparatus a fine polish and to cover this surface with lacquer; it is now becoming more generally customary to bronze them or to stain them either black or brown; these are, in fact, but modifications of one process.

To obtain the golden orange color characteristic of brasses rich in copper, the piece may be polished and immersed in a warm bath of the neutral solution of crystallized acetate of copper for a moment, washing in clean water and rubbing dry and bright. The chloride of antimony gives a dark rich violet color, if the article is heated to nearly the boiling point of water; sulphate of copper gives a watered surface and copper nitrate a black.

Larkin used the hydrochlorate of copper with a little

free nitric acid, largely diluted, to produce a dark bronze; a little acetic acid added to the solution of the same salt gave a copper color, and the patina of antique bronze was imitated by adding ammonia solution in large amount, or a quantity of sal ammoniac.

"Bronze" paints are used for giving to the surface of iron, or of any other material, the appearance of bronze; they have a great variety of composition; some are composed of filings, or powder, of brass mixed in some oil paint which does not conceal the color of the bronze.

Graham's bronzing liquids, as published in 1861,* have a great range of composition and of application as follows:

BRONZING LIQUIDS.

To be used for Brass by simple Immersion.

No.	Water.	Nitrate of iron.	Perchloride of iron.	Permuriate of iron.	Nitrate of copper.	Tersulphide of arsenic.	Muriate of arsenic.	Potash solution of sulphur.	Pearlash solution.	Cyanide of potassium.	Ferrocyanide of potassium sol.	Sulphocyanide of potassium.	Hyposulphite of soda.	Nitric acid.	Oxalic acid.	
	pt.	dr.	dr.	pt.	oz.	gr.	oz.	dr.	dr.	oz.	pt.	dr.	dr.	dr.	oz.	
1	1	5	..	..	..	..	..	..	..	..	..	..	..	..	..	Brown, and every shade to black.
2	1	..	5	..	..	..	..	..	..	..	..	..	..	..	..	" "
3	1	16	..	..	..	..	..	..	..	..	..	..	16	..	..	Brown, and every shade to red.
4	1	..	..	..	..	..	..	..	..	..	..	..	16	1	..	" "
5	1	..	..	..	1	..	..	..	..	..	..	..	..	..	1	Brownish red.
6	..	..	..	..	..	..	..	..	..	..	1	..	..	3	..	"
7	1	..	..	..	..	..	..	..	..	1	..	..	..	4	..	Dark brown.
8	1	..	..	..	..	30	..	..	6	..	..	..	..	..	..	Yellow to red.
9	1	..	..	..	..	..	..	1	..	..	..	..	..	..	..	Orange.
10	2	..	..	1	..	..	..	..	..	..	..	..	..	..	..	Olive-green.
11	1	..	5	..	..	..	..	..	..	..	..	2	..	..	..	Slate.
12	1	..	..	..	..	..	..	..	..	..	..	..	20	..	..	Blue.
13	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	Steel-gray.
14	1	..	..	2	..	..	10	..	..	..	..	..	..	..	..	Black.

In the preparation of No. 5, the liquid must be brought to boil and cooled. In using No. 13, the heat of the liquid must not be under 180° F. No. 6 is slow in action, taking an hour to produce good results. The action of the others is, for the most part, immediate.

* Brass Founders' Manual, Lond. 1870.

To be used for Copper by simple Immersion.

No.	Water.	Nitrate of iron.	Sulphate of copper.	Sulphide of antimony.	Sulphur.	Muriate of arsenic.	Pearlash.	Sulphocyanide of potassium.	Hyposulphite of soda.	Hydrochloric acid.	
	pt.	dr.	oz.	dr.	dr.	dr.	oz.	dr.	oz.	dr.	
15	1	5	..	..	..	..	..	..	..	..	Brown, and every shade to black.
16	1	5	..	..	..	..	..	2	..	..	Dark-brown drab.
17	1	..	1	..	..	..	..	..	1	2	" "
18	1	..	..	2	..	..	1	..	..	..	Bright red.
19	1	..	..	..	1	..	1	..	..	..	Red, and every shade to black.
20	1	..	..	..	..	1	..	..	..	..	Steel-gray, at 180° F.

For Zinc.

No.	Water.	Nitrate of iron.	Protochloride of tin.	Sulphate of copper.	Muriate of iron.	Muriate of Lead.	Pearlash.	Sulphocyanide of potassium.	Hyposulphite of soda.	Garancine infusion.	Logwood infusion.	
	pt.	dr.	dr.	dr.	dr.	oz.	oz.	dr.	dr.			
21	1	5	..	..	..	..	..	..	..	..	..	Black.
22	1	..	1	..	..	..	..	..	..	..	..	"
23	1	..	1	..	..	..	..	1	..	..	..	Dark gray.
24	2	..	..	1	1	*	..	..	..	..	..	"
25	..	..	..	..	..	..	..	..	..	..	..	"
26	2	..	..	..	1	..	..	..	..	..	..	Green-gray.
27	..	..	..	..	..	..	..	..	..	×	..	Red —— boil.
28	1	..	..	4	..	..	4	..	..	..	..	Copper color. Plates so c ∧ z.
29	1	..	..	8	..	..	..	..	8	..	..	Copper color, with agitation.
30	..	..	..	..	..	..	..	..	..	..	×	Purple —— boil.

Lacquering is the process of covering a polished surface of brass or of other metal with a transparent or translucent coating, which, while protecting it from oxidation and

* Made to the consistency of cream.

discoloration, does not wholly conceal it. It is a process of varnishing polished metal. It is applied also to the surfaces of bronzed objects. Lacquer is a solution, usually, of some vegetable gum or resin in alcohol or other effective colorless solvent. In its application, great care is taken to keep the piece to be lacquered warm and of uniform temperature, to apply the solution quickly, smoothly and uniformly. The usual solution is "shellac" in alcohol, and the best can, as a rule, be made with the "stick" lac. It may be colored by any permanent transparent alchoholic solution giving the desired tint. The red coloring matters are, usually, dragon's blood, red saunders or annotto; the yellow are gamboge, sandarac, saffron, turmeric or aloes. The following is Graham's table of lacquers:

LACQUERS.

No	Shellac.	Mastic.	Canada Balsam.	SOLUTIONS.					REDS.			YELLOW.					
				Spirits of wine.	Pyro-acetic ether.	Spirits of turpentine.	Turpentine varnish.	Simple pale lacquer.	Dragon's blood.	Annotto.	Saunders.	Turmeric.	Gamboge.	Saffron.	Cape Aloes.	Sandarac.	
	oz.	dr.	dr.	pt.	oz.	dr	oz.	pt.	dr.	dr.	gr.	dr.	dr.	dr.	dr.	dr.	
1	4	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	Strong simple.
2	1	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	Simple pale.
3	1	..	..	1	..	..	..	..	..	..	..	..	1	..	3	..	Fine pale.
4	1	..	..	1	..	..	..	..	..	..	..	1	1	2	..	..	"
5	1	..	..	2	..	..	..	..	1	1	..	..	16	4	..	8	"
6	2	..	..	2	..	..	..	..	1	8	..	32	..	..	..	8	Plate gold.
7	2	..	..	1	..	..	..	..	..	..	..	..	2	..	4	..	Pale yellow.
8	5	..	..	3	30	..	..	..	..	..	..	..	..	..	..	..	" Ross's.
9	..	..	..	..	..	..	..	1	..	1	..	4	..	..	..	..	Full yellow.
10	3	..	..	1	..	..	..	..	..	2	..	10	..	2	..	..	Gold.
11	3	..	..	4	..	..	6	..	..	..	..	64	6	..	..	14	"
12	1	..	..	1	..	..	..	..	..	..	..	20	..	..	2	5	"
13	3	..	..	1	..	..	..	..	4	..	..	16	..	..	..	..	Deep gold.
14	3	..	..	1	..	..	..	..	4	..	..	1	..	..	..	..	"
15	3	..	..	1	..	30	..	..	40	..	12	10	..	..	..	..	"
16	..	..	..	..	..	..	..	1	8	32	..	..	..	..	..	..	Red.
17	1	..	..	..	..	..	1	..	8	24	..	..	..	..	..	27	"
18	15	30	30	6	..	..	..	..	20	..	..	60	..	10	..	..	Tin lacquer.
19	..	..	..	..	..	..	..	1	..	..	..	4	1	..	..	..	Green, for bronze.

The union of red with yellow produces a fine orange color.

The lacquers are kept in carefully stoppered bottles, and it is better that they should be of opaque material, or of glass impenetrable by actinic light capable of altering them; yellow glass is sometimes used. When in use, they are poured into dishes of convenient size and form and are laid on with a thin, wide flat brush.*

"Clouding" is performed by pouring on the surface a mixture of fine charcoal dust in water, stirring it to obtain the pattern, and then drying. The work is finally lacquered.

* See "Materials of Engineering" for lacquers and browning liquids for fire-arms, etc.

CHAPTER XII.

STRENGTH, ELASTICITY AND DUCTILITY OF METALS.

The Strength of the Useful Metals and other mechanical properties have not attracted as much attention as the engineer would desire. Investigations have been few in number relating to soft metals, and as a rule unfruitful, in comparison with those relating to iron and steel.

In recording and discussing experimental work on the various metals and their alloys, the system and nomenclature adopted will be that employed in the study of the strength of other materials. The following summary will here suffice.* Following it, will be given a statement of the results of experiments made upon all the "useful" metals, succeeded by chapters describing investigations of the strength and elasticity of their alloys, and the conditions modifying strength.

The Resistance of Metal to rupture may be brought into play by either of several methods of stress, which have been thus divided by the Author:

Longitudinal.....	Tensile : resisting pulling force. Compression : resisting crushing force.
Transverse.....	Shearing : resisting cutting across. Bending : resisting cross breaking. Torsional : resisting twisting stress.

* Abridged and adapted from Part II., M. of Eng. For the theory of the elasticity and strength of materials, consult "Wood's Resistance of Materials," published by J. Wiley & Sons, and Burr's work on the same subject issued by the same publishers.

When a load is applied to any part of a structure or of a machine it causes a change of form, which may be very slight, but which always takes place, however small the load. This change of form is resisted by the internal molecular forces of the piece, *i.e.*, by its cohesion. The change of form thus produced is called *strain*, and the acting force is a *stress*.

The *Ultimate Strength* of a piece is the maximum resistance under load—the greatest stress that can exist before rupture. The *Proof Strength* is the load applied to determine the value of the material tested when it is not intended that observable deformation shall take place. It is usually equal, or nearly so, to the maximum elastic resistance of the piece. It is sometimes said that this load, long continued, will produce fracture; but, as will be seen hereafter, this is not necessarily, even if ever, true.

The *Working Load* is that which the piece is proportioned to bear. It is the load carried in ordinary working, and is usually less than the proof load, and is always some fraction, determined by circumstances, of the ultimate strength.

A *Dead Load* is applied without shock, and, once applied, remains unchanged, as, *e.g.*, the weight of a bridge; it produces a uniform stress. A *Live Load* is applied suddenly, and may produce a variable stress, as, *e.g.*, by the passage of a railroad train over a bridge.

The *Distortion* of the strained piece is related to the load in a manner best indicated by strain diagrams. Its value as a factor of the measure of shock-resisting power, or of resilience, is exhibited in a later article. It also has importance as indicating the ductile qualities of the metal.

The *Reduction of Area of Section* under a breaking load is similarly indicative of the ductility of the material, and is to be noted in conjunction with the distortion.

E.g. A considerable reduction of section with a smaller proportional extension would indicate a lack of homogeneousness, and that the piece had broken at a weak part of the bar. The greater the extension in proportion to the reduction of area in tension, the more uniform the character of the metal.

Factors of Safety.—The ultimate strength, or maximum capacity for resisting stress, has a ratio to the maximum stress due to the working load, which, although less in metal than in wooden or stone structures, is, nevertheless, made of considerable magnitude in many cases. It is much greater under moving than under steady "dead" loads, and varies with the character of the material used. For machinery it is usually 6 or 8; for structures erected by the civil engineer, from 5 to 6. The following may be taken as minimum values of this "factor of safety for the non-ferrous metals:"

MATERIAL.	LOAD.		SHOCK.	
	Dead.	Live.		
Iron and steel.....	3	6	8	
Copper and other soft metals and alloys.....	5	8	10 +	Ratio of Ultimate Strength to Working Load.
The brittle metals and alloys.	4	7	10 to 15	

The Proof Strength usually exceeds the working load from 50 per cent., with tough metals, to 200 or 300 per cent. where brittle materials are used. It should usually be below the elastic limit of the material.

As this limit, with brittle materials, is often nearly equal to their ultimate strength, a set of factors of safety, based on the elastic limit, would differ much from those above given for ductile metals, but would be about the same for all brittle materials, thus:

MATERIAL.	LOAD.		SHOCK.	
	Dead.	Live.		
Iron and steel.....	1	2	3	Ratio of Elastic Resistance to Working Load.
Soft metals.....	2	4	6	
Brittle metals and alloys....	3	6	8 to 12	

The figure given for shock is to be taken as approximate, but used only when it is not practicable to calculate the energy of impact and the resilience of the piece meeting it, and thus to make an exact calculation of proportions.

The factors of safety adopted for non-ferrous metals are higher than those usually adopted for construction in iron or steel in consequence of the fact that the elastic limit and the elastic resilience, or shock-resisting power, of the latter seem to increase with strain, up to a limit; while the former gradually yield under comparatively low stresses, as will be seen hereafter. In common practice, the factor of safety covers not only risks of injury by accidental excessive stresses, but deterioration with time, uncertainty as to the character of uninspected material, and sometimes equally great uncertainty as to the absolute correctness of the formulas and the constants used in the calculations. As inspection becomes more efficient and trustworthy; as our knowledge of the effect of prolonged and of intermittent stress becomes more certain and complete; as our formulas are improved and rationalized, and as their empirically determined constants are more exactly obtained, the factor of safety is gradually reduced, and will finally become a minimum when the engineer acquires the ability to assume with confidence the conditions to be estimated upon, and to say with precision how his materials will continuously carry their loads.

A characteristic distinction between the ductile non-ferrous metals and ductile iron or steel, is that the former have usually, as purchased, no true elastic limit, but yield to small stresses without recovery of form and their permanent set equals their maximum distortion. Where brittle, they are often very elastic, however, and recover fully. In such cases, the elastic limit coincides with their ultimate resistance to fracture, as is the case with glass, hard cast iron, and often with hardened steel.

In the table above it is assumed that an elastic limit occurs at the point at which the elongation becomes 0.0010 of the total length of the piece stretched.

In some cases it is advisable to design some minor part, or element, of a train with a lower factor of safety, to insure that when a breakdown does occur it shall be certain to take place where it will do least harm.

The Measure of Resistance to *strain* is determined, in form, by the character of the *stress*. By stress is here understood the force exerted, and by strain the change of form produced by it.

Tenacity is resistance to a pulling stress, and is measured by the resistance of a section, one unit in area, as in pounds or tons on the square inch, or in kilogrammes per square centimetre or square millimetre. Then, if T represents the tenacity and K is the section resisting rupture, the total load that can be sustained is, as a maximum,

$$P = TK$$

Compression is similarly measured, and if C be the maximum resistance to crushing per unit of area, and K the section, the maximum load will be

$$P = CK$$

Shearing is resisted by forces expressed in the same way, and the maximum shearing stress borne by any section is

$$P = SK$$

Bending Stresses are measured by moments expressed by the product of the bending effort into its lever-arm about the section strained, and if P is the resultant load, l the lever-arm and M the moment of resistance of the section considered,

$$Pl = M$$

Torsional Stresses are also measured by the moment of the stress exerted, and the quantity of attacking and resisting moments is expressed as in the last case.

Elasticity is measured by the longitudinal force, which, acting on a unit of area of the resisting section, if elasticity were to remain unimpaired, would extend the piece to double its original length. Within the limit at which elasticity is unimpaired, the variation of length is proportional to the

force acting, and if E is the "*Modulus of Elasticity*," or "Young's Modulus," l the length, and e the extension, P being the total load, and K the section:

$$E = \frac{Pl}{eK}$$

$$e = \frac{Pl}{EK}$$

The Coefficients entering into these several expressions for resistance of materials are often called *Moduli*, and the forms of the expressions in which they appear are deduced by the Theory of the Resistance of Materials, and the processes are given in detail in works on that subject.

These moduli, or coefficients, as will be seen, have values which are rarely the same in any two cases; but vary not only with the kind of material, but with every variation, in the same substance, of structure, size, form, age, chemical composition or physical character, with every change of temperature, and even with the rate of distortion and method of action of the distorting force. Values for each familiar material, for a wide range of conditions, will be given in the following pages.

Method of Resistance to Stress.—When a piece of metal is subjected to stress exceeding its power of resistance for the moment, and gradually increasing up to the limit at which rupture takes place, it yields and becomes distorted at a rate which has a definitely variable relation to the magnitude of the distorting force; this relation, although very similar for all metals of any one kind, differs greatly for different metals, and is subject to observable alteration by every measurable difference in chemical composition or in physical structure.

Thus, in Fig. 55, let this operation be represented by the several curves, *a*, *b*, *c*, *d*, etc., the elevation of any point on the curve above the axis of abscissas, *OX*, being made proportional to the resistance to distortion of the piece, and to the equivalent distorting stress, at the instant when its dis-

tance from the left side of the diagram, or the axis of ordinates, OY, measures the coincident distortion. As drawn, the strain-diagram, $a\,a'$, is such as would be made by a soft metal like tin or lead; $b\,b'$ represents a harder, and $c\,c'$ a still harder and stronger metal, as zinc and rolled copper. If the smallest divisions measure the per cent. of extension horizontally, and 10,000 pounds per square inch (703 kilogrammes per square centimetre) vertically, $d\,d'$, would fairly represent a hard iron, or a puddled or a "mild" steel; while $f\,f'$ and $g\,g'$ would be strain diagrams of hard, and of very hard tool steels, respectively.

The points marked e, e', e'', etc., are the so-called "*elastic*

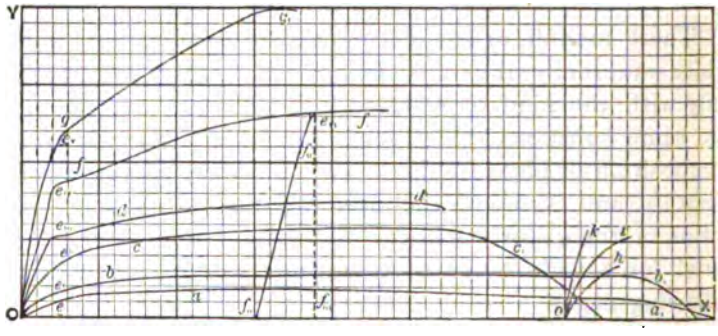

FIG. 55.—STRAIN-DIAGRAMS.

limits," at which the rate of distortion more or less suddenly changes, and the elevation becomes more nearly equal to the permanent change of form, and at these points the resistance to further change increases much more slowly than before. This change of rate of increase in resistance continues until a maximum is reached, and, passing that point, the piece either breaks, as at f' and g', or yields more and more easily until distortion ceases, or until fracture takes place, and it becomes zero at the base line, as at X.

Such curves have been called by the Author "Strain-diagrams."

Equations of Curves of Resistance or Strain-diagrams.—These curves are, at the start, often nearly para-

bolic, and the strain-diagrams of cast iron, *h*, *i*, *k*, having their origin at *o*, are usually capable of being quite accurately expressed by an equation of the parabolic form, as

$$P = A\frac{e}{l} - B\frac{e^2}{l^2}$$

in which $\frac{e}{l}$ is the ratio of elongation to the length of the piece, and P the load per unit of area. The constants may be taken as:

Material.	A		B	
	British.	Metric.	British.	Metric.
Cast Iron.....	14,000,000	984,000	3,000,000,000	211,000,000
Forged Iron..	25,000,000	1,758,000	125,000,000	8,800,000
Soft "Steels".....	25,000,000	1,758,000	125,000,000	8,800,000
Tool Steels.....	30,000,000	2,109,000	1,000,000,000	70,300,000
Brass and Bronze.....	12,000,000	844,000	50,000,000	3,500,000
Copper.....	10,000,000	703,000	100,000,000	7,000,000

The coefficient A is the modulus or coefficient of elasticity.

Such expressions as that above given, the constants being determined, for each case, by experiment, may be made to represent the method of variation of resistance with increasing distortion with every method of strain. The equations, therefore, the relation between ordinate and abscissa being algebraically expressed, may be made to form a means of integrating the area $\int y\,dx$, and determining its magnitude.

The Series of Elastic Limits.—If, at any moment, the stress producing distortion is relaxed, the piece recoils and continues this reversed distortion until, all load being taken off, the recoil ceases and the piece takes its "permanent set." This change is shown in the figure at $f''\,f''$, the gradual reduction of load and coincident partial restoration of shape being represented by a succession of points forming the line $f''\,f''$, each of which points has a position which is determined by the elastic resistance of the piece as

now altered by the strain to which it has been subjected. The distance $O f''$ measures the permanent set, and the distance $f'' f'''$ measures the recoil.

The piece now has qualities which are quite different from those which distinguished it originally, and it may be regarded as a new specimen and as quite a different metal. Its strain-diagram now has its origin at f'', and the piece being once more strained, its behavior will be represented by the curve $f'' f'' e^{VI} f'$, a curve which often bears little resemblance to the original diagram O, f, f'. The new diagram shows an elastic limit at e^{V}, and very much higher than the original limit e^{IV}. Had this experiment been performed at any other point along the line $f f'$, the same result would have followed. It thus becomes evident that the strain-diagram is a curve of elastic limits, each point being at once representative of the resistance of the piece in a certain condition of distortion, and of its elastic limit as then strained.

The ductile, non-ferrous metals, and iron and steel, and the truly elastic substances, have this in common—that the effect of strain is to produce a change in the mode of resistance to stress, which results, in the latter, in the production of a new and elevated elastic limit, and in the former in the introduction of such a limit where none was observable before.

It becomes necessary to distinguish these elastic limits in describing the behavior of strained metals, and, as will be seen subsequently, the elastic limits here described are, under some conditions, altered by strain, and we thus have another form of elastic limit to be defined by a special term.

In this work the original elastic limit of the piece in its ordinary state, as at e, e', e'', etc., will be called either the *Original*, or the *Primitive*, *Elastic Limit*, and the elastic limit corresponding to any point in the strain-diagram produced by gradual, unintermitted strain, will be called the *Normal Elastic Limit* for the given strain. It is seen that the diagram representing this kind of strain is a *Curve of Normal Elastic Limits.*

The elastic limit is often said to be that point at which

a permanent set takes place. As will be seen on studying actual strain-diagrams to be hereafter given, and which exhibit accurately the behavior of the metal under stress, there is no such point. The elastic limit referred to ordinarily, when the term is used, is that point within which *recoil*, on removal of load, is approximately equal to the elongation attained and beyond which *set* becomes nearly equal to total elongation.

It is seen that, within the elastic limit, sets and elongations are similarly proportional to the loads, that the same is true on any elastic line, and that loads and elongations are nearly proportional everywhere beyond the elastic limit, within a moderate range, although the total distortion then bears a far higher ratio to the load, while the sets become nearly equal to the total elongations.

Effect of Shock or Impact; Resilience.—The behavior of metals, under moving, or "live," load and under shock, is not the same as when gradually and steadily strained by a slowly applied or static stress. In the latter case, the metal undergoes the changes illustrated by the strain diagrams, until a point is reached at which equilibrium occurs between the applied load and resisting forces, and the body rests indefinitely, as under a permanent load, without other change occurring than such settlement of parts as will bring the whole structural resistance into play.

When a freely moving body strikes upon the resisting piece, on the other hand, it only comes to rest when all its kinetic energy is taken up by the resisting piece; there is then an equality of *vis viva* expended and work done, which is expressed thus:

$$\frac{WV^2}{2g} = \int_0^s p\,dx = p_m s;$$

in which expression W is the weight of the striking body, V its velocity, p the resisting force at any instant, p_m the mean resistance up to the point at which equilibrium occurs, and s is the distance through which resistance is met.

As has been seen, the resistance may usually be taken as varying approximately with the ordinates of a parabola, the abscissas representing extensions. The mean resistance is, therefore, nearly two-thirds the maximum, and

$$\frac{WV^2}{2g} = \int_0^e p\,dx = p_m s = \tfrac{2}{3}\,et = ae^2, \text{ nearly}$$

where e is the extension, and t the maximum resistance at that extension, and a a constant. Brittle materials, like hard bronzes and brasses, have a straight line for their strain-diagrams, and the coefficient becomes $\frac{1}{2}$ instead of $\frac{2}{3}$, and

$$\frac{WV^2}{2g} = ae^2 = \tfrac{1}{2}\,et = \tfrac{1}{2}\,\frac{t^2}{E}$$

Resilience, or Spring, is the work of resistance up to the elastic limit. This will be called *Elastic Resilience.* The modulus of elasticity being known, the Modulus of Elastic Resilience is obtained by dividing half the square of the maximum elastic resistance by the modulus of elasticity, E, as above, and the work done to the "primitive elastic limit" is obtained by multiplying this modulus of resilience by the volume of the bar.*

The total area of the diagram, measuring the total work done up to rupture, will be called a measure of *Total* or *Ultimate Resilience.* Mallett's Coefficient of Total Resilience is the half product of maximum resistance into total extension. It is correct for brittle substances and all cases in which the primitive elastic limit is found at the point of rupture. With tough materials, the coefficient is more nearly two-thirds—and may be even greater where the metal is very ductile, as, *e.g.*, pure copper, tin, or lead. Unity of length and of section

* Rankine and some other writers take this modulus as $\frac{t^2}{E}$, instead of $\frac{1}{2}\frac{t^2}{E}$.

being taken, this coefficient is here called the Modulus of Resilience.

When the energy of a striking body exceeds the total resilience of the material, the piece will be broken. When the energy expended is less, the piece will be strained until the work done in resistance equals that energy, when the striking body will be brought to rest.

As the resistance is partly due to the *inertia* of the particles of the piece attacked, the strain-diagram area is always less than the real work of resistance, and, at high velocities, may be very considerably less, the difference being expended in the local deformation of that part of the piece at which the blow is received. In predicting the effect of a shock it is, therefore, necessary to know not only the energy stored in the moving mass and the method of variation of the resistance, but also the striking velocity. To meet a shock successfully it is seen that resilience must be secured sufficient to take up the shock without rupture, or, if possible, without serious deformation. It is, in most cases, necessary to make the *elastic* resilience greater than the maximum energy of any attacking body.

Moving Loads produce an effect intermediate between that due to static stress and that due to the shock of a freely moving body acting by its inertia wholly; these cases are, therefore, met in design by the use of a high factor of safety, as above.

As is seen by a glance at the strain-diagram, *ff*, (Fig. 55), the piece once strained has a higher elastic resilience than at first, and it is therefore safer against permanent distortion by moderate shocks, while the approach of permanent extension to a limit renders it less secure against shocks of such great intensity as to endanger the piece.

When the shock is completely taken up, the piece recoils, as at $e^{vi}f''f''$, until it settles at such a point on that line—assuming the shock to have extended the piece to the point e^{vi}—that the static resistance just equilibrates the static load. This point is usually reached after a series of vibrations on either side of it has occurred. With perfect elasticity, this

point is at one-half the maximum resistance, or elongation, attained. Thus we have

$$\int_o^s p\,dx = \frac{WV^2}{2g}$$

but p varies as x within the elastic limit, which limit has now risen to some new point along the line of normal elastic limits, as e^{vi}. Taking the origin at the foot of $f''f''$, since the variations of length along the line Ox are equal to the elongations and to the distances traversed as the load falls, and as stresses are now proportional to elongations,

$$p=ax;\ Wh=Ws;\ \text{and}\ W=P$$

when the resisting force is p, the elongations x, while h and s are maximum fall and elongation, and P is the maximum resistance to the load at rest. Then

$$\int_o^s p\,dx=a\int_o^s x\,dx=\frac{a}{2}s^2=Ws\therefore s=\frac{2W}{a}$$

For a static load, if s' is the elongation,

$$W=P=as'\ \therefore\ s'=\frac{W}{a}.$$

Hence,

$$\frac{s'}{s}=\tfrac{1}{2}$$

and the extension and the corresponding stress due to the sudden application of a load are double those produced by a static load.

The Variation of Form of Test-Piece so considerably modifies the apparent tenacity of iron and steel that it is necessary to note the size and shape of the specimen tested. When a piece of metal is subjected to stress and slowly pulled asunder, it will yield at the weakest section first, and if that section is of considerably less area than adjacent parts,

Fig. 56, or if the metal is not ductile, it will often break sharply, and without stretching appreciably, as seen in Fig. 58; the fractured surface will have a granular appearance, and the behavior of the piece, as a whole, may be like that of a brittle casting, even although actually made of tough and ductile metal, when the piece is deeply scored

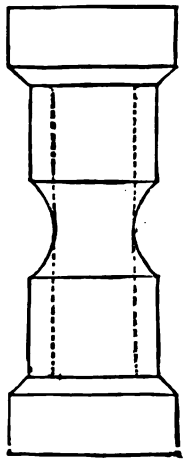

FIG. 56.—Incorrect.

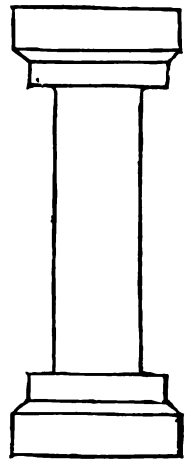

FIG. 57.—Correct.

FORMS OF TEST PIECES FOR TENSION.

When a bar of very ductile metal, of perfectly uniform cross-section, Fig. 57, is broken, on the other hand, it will, at first, if of uniform quality, gradually stretch with a nearly uniform reduction of section from end to end. Toward the ends, where held by the machine, this reduction of area is less perceivable, and on the extreme ends where no strain can occur, except from the compressing action of the grips, the original area of section is retained, diminution taking place from that point to the most strained part by a gradual taper or by a sudden reduction of section, according to the method adopted of holding the rod. When the stress has attained so great an intensity that the weakest section is strained beyond its elastic limit, "flow" begins there, and,

while the extension of other parts continues slowly, the portions immediately adjacent to the overstrained section stretch more and more rapidly as this local reduction of section continues, and finally fracture takes place. This locally reduced portion of the rod has a length which is dependent upon the character of the metal and the size of the piece.

FIG. 58.

Hard and brittle materials exhibit very little reduction and the reduced portion is short, as in Fig. 58; ductile and tough metals exhibit a marked reduction over a length of several diameters, and great reduction at the fractured section, as seen in Fig. 59. Of the samples shown in the figures, the first is of a good, but a badly worked, iron, and the second from the same metal after it had been more thoroughly worked.

When the breaking section is determined by deeply grooving the test-piece, the results of test are higher by 5 or 10 per cent. than when the cylinders are not so cut, if the metal is hard and brittle, and by 20 to 25 per cent. with tough and ductile irons or steels. In ordinary work this difference will average at least 20 per cent. with the ductile metals. A good bridge or cable iron in pieces of 1 inch (2.54 centimetres) diameter cut from 2-inch (5.08 centimetres) bar, exhibited a tenacity of 50,000 pounds per square inch in long test-pieces, and 60,000 in short grooved specimens (3,515 to 4,218 kilogrammes per square centimetre). Cast irons will give practically equal results by both tests, as will hard steels and very coarse-grained hard wrought irons.

Since these differences are so great that it is necessary to ascertain the form of samples tested before the results of test can be properly interpreted, it becomes advisable to use a test-piece of standard shape and size for all tests the results of which are to be compared. The figures given hereafter, when not otherwise stated, may be assumed to apply to pieces

of one half square inch area (3.23 square centimetres) of section, and at least 5 diameters in length. This length is usually quite sufficient, and is taken by the Author as a minimum. For other lengths, the extension is measured by a constant function of the total length plus a function of the diameter, which varies with the quality of the metal and the shape of the test-piece. It may be expressed by the formula

$$e = al + f(d)$$

FIG. 59.

The elongation often increases from 20 up to 40 per cent., as the test-piece is shortened from 5 inches(12.7 centimetres) to ½ inch (1.27 centimetres) in length, while the contraction of section is, on the other hand, decreased from 50 down to 25 per cent., nearly. Fairbairn,* testing good round bar-iron, found that the extension for lengths varying from 10 inches (25.4 centimetres) to 10 feet (3.28 metres) could be expressed, for such iron, by the formula

$$e = 18 + \frac{25}{l}$$

where l is the length of bar in inches. In metric measures this becomes

$$e = 18 + \frac{63.5}{l};$$

l = length in centimetres; e = elongation per unit of length.

This influence of form is as important in testing soft steels as in working on iron. Col. Wilmot, testing Bessemer "steel" at the Woolwich Arsenal, G. B., obtained the following figures:

* *Useful Information*, Second series, p. 301.

Form.	Test-piece.	Tenacity: Lbs. per sq. in.	; kilogs per sq. cm.
Grooved, Fig. 56,	Highest	162,974	11,457
	Lowest	136,490	9,595
	Average	153,677	10,803
Long cylinder	Highest	123,165	8,658
	Lowest	103,255	7,259
	Average	114,460	8,047

The difference amounts to between 30 and 35 per cent., the groove giving an abnormally high figure.

It is evident from the above that the elongation must be proportionably much greater in short specimens than in long pieces. This is well shown in this table of tests made by Beardslee, for the United States Board.*

TESTS OF TEST-PIECES OF VARYING PROPORTIONS—TENSION.

Number.	Length.		Per cent. of elongation.	Diameter.		Per cent. of contraction of area	Stress when piece began to stretch observably.		Breaking-stress.		Remarks.
	Original.	Final.		Original.	Reduced.		Observed stress.	Stress per square inch.	Observed stress.	Stress per square inch.	
	In.	*In.*		*In.*	*In.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	
1	5.000	6.522	30.0	.798	.568	49.3	13,400	26,800	26,002	51,089	Elastic limit, 26,795 lbs. per sq. in.
2	3.938	5.204	32.0	.798	.564	50.0	14,000	28,000	26,200	52,389	Elastic limit, 28,194 lbs. per sq. in.
3	4.500	5.853	30.0	.797	.584	46.3	14,000	28,290	26,190	52.495	Elastic limit, 28,062 lbs. per sq. in.
4	3.500	4.615	31.6	.791	.570	48.0	13,000	26,450	26,070	53.052	Elastic limit, 27,268 lbs. per sq. in.
5	3.000	3.977	33.0	.792	.571	48.0	14,000	28,420	26,10	52,984	
6	2.472	3.266	32.1	.799	.589	45.6	14,000	27,920	26,500	52.852	
7	1.989	2.644	32.9	.798	.591	45.0	14,000	28,000	26,500	53,169	
8	1.500	2.026	35.0	.797	.590	45.2	15,500	31,320	26,275	52,666	
9	1.000	1.354	35.4	.798	.600	43.5	16,675	33,350	26,590	53,169	
10	0.500	0.708	41.6	.798	.635	36.6	18,760	37,520	28,665	57,318	

With such brittle materials as the cast irons, the difference becomes unimportant. Beardslee found a difference of but 1 per cent. in certain cases. The more brittle the material the less this variation of the observed tenacity.

As will be seen later, even more important variations follow changes of proportion of pieces in compression. No test-piece should be of very small diameter, as inaccuracy is

* Report, p. 104.

more probable with a small than with a large piece, and the errors are more likely to be increased in reduction to the stress per square inch. The length should not be less than four times the diameter in any case, and with soft, ductile metal, five or six diameters would be preferable for tension.

Where much work is to be done, it is quite important that a set of standard shapes of test pieces should be selected, and that all the tests should be made upon samples worked to standard size and form. Thus, tension-pieces are often made of the shapes seen in the figure, when testing square, cylindrical, or flat samples, or samples cut from the solid. The last is a shape called for under the U. S. inspection laws when testing boiler-plate; but it should never be used, if choice is permitted, as it gives no chance of stretching, and is therefore nearly useless as a gauge of the quality of the metal; it will undoubtedly be abandoned in course of time, as it invariably gives too high a figure, and does not distinguish the hard and brittle from the better and tougher materials which are desired in construction.

The dimensions adopted by the Author are one-half square inch (3.23 square centimetres) section for all metals except the tool steels (0.798 inch; 2 centimetres diameter, when round), and one-eighth or one-quarter square inch (0.81 to 1.61 square centimetres area; 0.398 or 0.565 inch 1 or 1.4 centimetres diameter) for the latter, at the smallest cross-section. Kent, who sketches the above, takes these shapes, making them, if of tool steel, $\frac{11}{16}$ inch diameter (1.75 centimetre), or $\frac{3}{8}$ square inch (2.44 square centimetres) area;

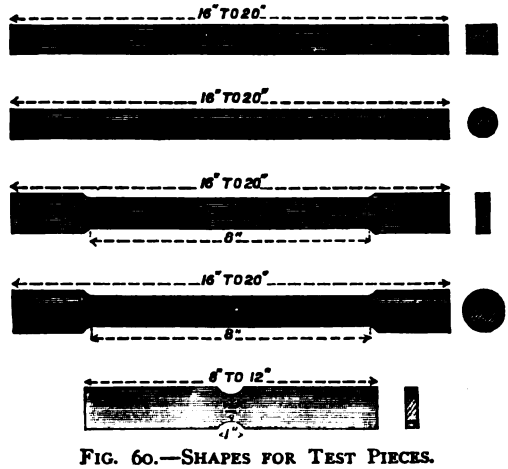

FIG. 60.—SHAPES FOR TEST PIECES.

in other metals either ¾-inch (1.9 centimetres) diameter or 0.44 square inch (2.84 square centimetres), or as above. The edges should be true and smooth, and the fillets ¼-inch radius.

For compression tests of metal, 1 inch (2.54 centimetres) long and ½-inch (1.27 centimetres) diameter, ends perfectly square, is recommended. For stone and brick, a 2-inch (5.08 centimetres) cube. Transverse test-pieces should not be less than 1 foot, nor more than 4 feet in length, when to be handled in ordinary machines.

The standard specimen will be taken as above, and good wrought iron of such shape and size should exhibit a tenacity of at least 50,000 pounds (3,515 kilogrammes per square centimetre) if from bars not exceeding 2 inches (5.08 centimetres) diameter, and should stretch 25 per cent. with 40 per cent. reduction of area. Such test-pieces have the advantage of giving uniform comparable and minimum figures for tenacity, and of permitting accurate determinations of elongation.

Test-pieces are only satisfactory in form when turned in the lathe, as the coincidence of the central line of figure with the line of pull is thus most perfectly insured. When, as with sheet metal, this cannot be done readily, care must be taken to secure proportions of length and cross-section as nearly alike those of the standard test-piece as possible, and to secure symmetry and exactness of form and dimension; such pieces are liable to yield by tearing when not well made and properly adjusted in the machine.

The Method of Use of Testing Machines is, in general, the same for all cases, and is only modified by methods of holding the piece and of taking measurements which may be peculiar to the machine used.

The piece being carefully adjusted in the clamps, and the measuring apparatus so attached that its indications may be relied upon, and that it is not likely to be injured by any accident during the test, the load is very slowly and steadily applied. At intervals, readings of elongation and of load are taken and recorded, and the observer, noting their rate of increase, after a time detects a change in their ratio which indicates that the elastic limit is reached, and that extension is

taking place more rapidly with each accession of load. The fracture of the piece can usually be anticipated, and the measuring apparatus is removed before danger is incurred of its injury by the shock of breaking. With brittle materials the final break takes place suddenly, and without warning. The observer must therefore depend upon his knowledge that such material is likely to break at not far from a known load. Ductile substances usually pass a limit of maximum load, and break after stretching an appreciable amount with gradually diminishing resistance.

When "sets" are to be measured, all load is removed at intervals during the test, and the piece is permitted to recoil. The difference between its length now unloaded and the original length, is the "set." This set is usually partly temporary, and the piece, if left unloaded, will often very slowly contract for a considerable time, thus perceptibly reducing the set, which then becomes permanent. It is not advisable to take measurements of set unless for a special purpose, as each relaxation of the piece modifies its resisting power, and makes comparison with other samples less easy and satisfactory.

When broken, the pieces are removed from the machine, their final length is measured, and they are carefully examined to obtain such knowledge of the quality of the metal as may be secured by a study of their texture and of the character of their fracture.

The Method of Record is a matter of some importance in making researches relating to the strength of materials. The Author has been accustomed to use printed blanks for such work. The following are the headings adopted.

Of these blanks, the first is used indifferently for either tension or compression, and the last for miscellaneous purposes.

An examination of the records to be given in the following pages will show that the customs of the various departments, as well as of individual investigators, differ greatly, not only in the extent to which the minuteness of measurement is carried, but also in their methods of securing results and recording them. The columns in the blanks here given are not always all filled out.

MATERIAL. ..... *INVESTIGATION.* .....

I.—RECORD OF TESTS BY TENSION OF .....

NAME.	SOURCE.	NO.	ORIGINAL MARK.	DIMENSIONS. ORIGINAL AND FINAL.				STRESSES.		PROOF LOAD PER UNIT AREA OF		BREAKING LOAD PER UNIT AREA		EXTENSION.		SPECIFIC GRAVITY. SG	MODULUS OF ELASTICITY. E	MODULUS OF RESILIENCE. W
				Length. L, L'	Breadth. b, b'	Depth. d, d'	Diameter. h, h'	Proof.	Ultimate.	Original section. P	Fractured section. P'	Original section. T	Fractured section. T'	Actual.	Ratio to Original Length.			

MATERIAL. ..... *INVESTIGATION.* .....

II.—RECORD OF TESTS BY TRANSVERSE STRESS OF .....

NAME.	SOURCE.	NO.	ORIGINAL MARK.	DIMENSIONS.				PROOF STRESSES.		DEFLECTION.	BREAKING LOAD.		EXTENSION (OF MOST EXTENDED FIBRE).		SPECIFIC GRAVITY. SG	MODULUS OF ELASTICITY.	MODULUS OF RESILIENCE. W
				Distance between Supports.	Breadth. b.	Depth. d.	Diameter. h.	Absolute. P'	Modulus. $R_1 = \frac{3P'l}{2bd^2}$	Actual. δ	Absolute. P	Modulus. $R = \frac{3Pl}{2bd^2\delta}$	Actual.	Ratio to Original Length.		$E = \frac{P/\delta}{48\frac{I}{l^3}}$	

MATERIAL.

.....
.....
.....
.....

III.—RECORD ACCOMPANYING AUTOGRAPHIC STRAIN DIAGRAMS OF

.....

INVESTIGATION.

.....
.....
.....
.....

NAME.	SOURCE.	NO.	ORIGINAL MARK.	SIZE FOR ESTIMATES.		STRESSES IN TORSION. MOMENT.		STRESSES IN TENSION APPROX. PER UNIT OF AREA.		RATIO OF EXTENSION.		HOMOGENEOUSNESS AS TO		MODULUS OF ELASTICITY. E	MODULUS OF RESILIENCE. W	MODULUS OF RESISTANCE TORSION. (A).			ANGLE.	
				Length. L	Diameter. D	Proof. M'	Ultimate. M	Proof. T'	Ultimate. T	Proof.	Maximum.	Structure.	Strain.			Elastic $A_E = \frac{ML}{D^4\theta}$	Proof $A' = \frac{M'}{D^3}$	Ultimate. $A = \frac{M}{D^3}$	Elastic θ_E	Ultimate θ_R

IV.—RECORD OF TESTS BY ..... STRESS OF

.....

ORIGINAL MARK. No.....				ORIGINAL MARK. No.....			
MATERIAL.....		*DIMENSIONS*.....		*MATERIAL*.....		*DIMENSIONS*.....	
.....		.....		.....		.....	
.....		.....		.....		.....	

225. Records of Tests.—The following are figures derived from such a test by tension, as made for the Author:

TEST OF WROUGHT IRON, LENGTH 8″ (19.32 CM.); DIAM., 0.798″ (2.03 CM.).

LOADS.		MICROMETER READINGS.		EXTENSIONS.		SETS.	
Actual.	Per sq. inch.			Actual.	Per Cent.	Actual.	Per Cent.
150	.....	.6600	.7913	.....	....	.....	.....
2,000	4,000	.6628	.7910	.0013	.016	.....	.....
4,000	8,000	.6637	.7922	.0023	.029	.....	.....
6,000	12,000	.6646	.7930	.0035	.044	.....	.....
8,000	16,000	.6606	.7946	.0050	.063	.....	.....
10,000	12,000	.6630	.7948	.0058	.073	.....	.....
150	.....	.6600	.7914	.....	....	.0001	.001
11,000	22,000	.6639	.7951	.0064	.030	.....	.....
12,000	24,000	.6700	.7953	.0070	.037	.....	.....
150	.....	.6603	.7915	.....	....	.0003	.004
13,000	26,000	.6715	.7967	.0080	.100	.....	.....
13,500	27,000	.6728	.7959	.0087	.109	.....	.....
14,000	28,000	.7242	.8424	.0577	.721	.....	.....
150	.....	.7133	.8351	.....	....	.0486	.608
15,000	30,000	.7535	.8712	.0867	1.084	.....	.....
150	.....	.7417	.8632	.....	.....	.0763	.960
17,000	34,000	.8474	.9618	.1790	2.238	.....	.....
150	.....	.8326	.9518	.....	.....	.1666	2.083
19,000	38,000	.9720	1.0856	.3032	3.790	.....	.....
150	.....	.9562	1.0732	.....	.....	.2391	3.613
21,000	42,000	1.1710	1.2811	.5004	6.255	.....	.....
150	.....	1.1524	1.2663	.....	.....	.4337	6.043
22,000	44,000	1.3303	1.4381	.6586	8.233	.....	.....
150	.....	1.3102	1.4212	.....	.....	.6401	8.001
22,500	45,000	1.4575	1.5441	.7752	9.690	.....	.....
23,000	46,000	1.5610	1.6670	.8834	11.105	.....	.....
23,500	47,000	1.7646	1.8693	1.0913	13.841	.....	.....
23,750	47,500	9.47		1.4700	18.375	.....	.....
21,800	43,600	9.54		1.5400	19.250	.....	.....

ELASTIC LIMIT.

Actual. Lbs.	Kgs.	Lbs. per sq. in.	Kgs. per sq. cm.
13,500	6140	27,000	1,898

BREAKING LOAD.

Original Sect.		Fractured Sect.	
Lbs. per sq. in.	Kgs. per sq. cm.	Lbs. per sq. in.	Kgs. per sq. cm.
47,500	3,340	69,840	4,910

Ultimate Elongation, per cent. of length = 19¼.
Reduction of Area, per cent., = 31.99.
Modulus of Elasticity = 24,365,000 lbs. on sq. in.
Modulus of Elasticity = 1,712,860 kilogrammes on sq. cm.

FINAL DIMENSIONS.

Length = 9″.54
Diameter = 0″.658

The following figures are derived from experiments upon good examples of several grades of iron plate.

Sixteen experiments upon high-grade boiler plate resulted as follows: *

	Measures.	
	Metric.	British.
Average breaking weight	3,803	54,123
Highest " "	4,007	57,012
Lowest " "	3,642	51,813
Variation in *per centum* of highest	9.1	

Fifteen experiments made upon the best grades of flange irons gave:

	Measures.	
	Metric.	British.
Average breaking weight	2,960	42,144
Highest " "	3,746	53,277
Lowest " "	2,320	33,003
Variation in *per centum* of highest	38	

Six experiments upon hard Bessemer steel gave:

	Measures.	
	Metric.	British.
Average breaking weight	5,877	83,621
Highest " "	6,087	86,580
Lowest " "	5,237	74,509
Variation in *per centum* of highest	14	

Five experiments were made upon the best boiler plate:

	Measures.	
	Metric.	British.
Average breaking weight	4,177	58,984
Highest " "	4,710	64,000
Lowest " "	3,887	55,300
Variation in *per centum* of highest	14	

Six experiments upon samples of tank-iron, by three makers, gave:

	Measures.	
	Metric.	British.
Average breaking weight, Maker No. 1	3,079	43,831
Highest " " " "	3,739	53,174
Lowest " " " "	2,538	36,111
Variation in *per centum* of highest	32	

* *Journal Franklin Institute*, 1872.

	Measures.	
	Metric.	British.
Average breaking weight, Maker No. 2	2,953	42,011
Highest " " "	3,392	48,425
Lowest " " "	5,510	35,679
Variation in *per centum* of highest.....	28	
Average breaking weight, Maker No. 3	2,896	41,249
Highest " " "	3,676	52,277
Lowest " " "	2,320	33,003
Variation in *per centum* of highest.....	38	

In another series, of which the results were supplied to the Author by Mr. C. Huston, the following figures were obtained:

TESTS OF BOILER-PLATE.

NAME.	TENACITY. *T*		ELASTIC LIMIT.	
	Lbs. per sq. inch.	Kilogs. per sq. cm.	Lbs. per sq. inch.	Kilogs. per sq. cm.
"Best boiled"..... ...	55,000	3,550	31,500	2,214
"Best flange charcoal".....	56,000	3,557	35,000	2,460
"Double-worked boiled"..	....	.....	40,000	2,812
"Best flange".....	56,400	3,560	30,000	2,109

The figures are all higher than those usually expected by the engineer when buying iron.

The last mentioned grade had a tenacity per square inch of fractured section of 87,000 pounds (5,673 kilogrammes per square centimetre), and was reduced in section 20 per cent.

Best "C. H. No. 1" plate, 3/8th inch (0.95 centimetre) thick, tested by Kent, exhibited a tenacity of very nearly 60,000 pounds per square inch (4,218 kilogrammes per square centimetre) of original area, elongated 15 per cent., and its

resistance per square inch of fractured section was 76,000 pounds (5,378 kilogrammes per square centimetre.)

Variations of Tenacity with Size.—Bar-irons exhibit a wide difference of strength, due to difference of section alone. This variation may be expressed approximately with good irons, such as the Author has studied in this relation, by the formulas,

$$\left.\begin{aligned} T &= 56{,}000 - 20{,}000 \log d \\ T_m &= 4{,}500 - 1{,}406 \log d_m \end{aligned}\right\}$$

Where T and T_m measure the tenacity in British and metric measures respectively, and d and d_m the diameter of the piece, or its least dimension.

Where it is desired to use an expression which is not logarithmic it will usually be safe to adopt in specifications the following:

$$T = \frac{60{,}000}{\sqrt[4]{d}}\,; \quad T_m = \frac{80{,}000}{\sqrt[4]{d}}$$

The Edgemoor Iron Company adopt, for wrought iron in tension, the formula,

$$T = 52{,}000 - \frac{7{,}000\,A}{B}\,,$$

in which A is the area, and B the periphery of the section.*

The experiments made by Beardslee for the United States Board gave results for rolled iron of various qualities, ranging from 60,000 to 46,000, according to size (¼ inch to 4 in.).

* *Ohio Railway Report*, 1881, p. 379.

TENACITY OF IRON WIRE.

NO.	ORIGINAL DIAMETER.		FINAL.		TENACITY.	
	Inches.	Centimetres.	Inches.	Centimetres.	Lbs. per sq. in.	Kilogs. per sq. cm.
10	.1340	.340	.1330	.338	92,890 *	6,530
11	.1205	.395	.1185	.303	84,442 †	5,936
12	.1040	.255	.1010	.257	93,158	6,555
13	.0925	.225	.0920	.234	100,297 *	7,050
14	.0800	.203	.0795	.203	94,299	6,629
15	.0710	.178	.0680	.173	98,384 ‡	6,915
16	.0640	.163	.0635	.161	93,876	6,600
17	.0535	.139	.0532	.135	105,871	7,442
18	.0465	.118	.0400	.101	119,536 §	8,403
19	.0385	.098	.0385	.098	87,617	6,159
20	.0335	.085	.0335	.085	111,184	7,816
21	.0290	.074	.0290	.074	113,546	7,982

The tenacity of "medium soft" telegraph wire may be taken as follows, for the several sizes obtainable in the market:

TENACITY OF IRON TELEGRAPH WIRE.

NO. B. W. G.	DIAMETER.		WEIGHT PER YARD OR METRE.		TENACITY. T'	
	In.	Cm.	Lbs.	Kilogs.	Lbs.	Kilogs.
1	0.30	0.76	0.688	0.313	4,000	1,800
2	0.28	0.70	0.599	0.272	3,400	1,500
3	0.26	0.66	0.517	0.235	2,900	1,300
4	0.24	0.61	0.440	0.200	2,500	1,150
5	0.22	0.56	0.370	0.170	2,200	1,000
6	0.20	0.50	0.305	0.139	1,800	800
7	0.19	0.48	0.262	0.119	1,500	650
8	0.17	0.43	0.221	0.100	1,200	550
9	0.16	0.40	0.184	0.084	950	440
10	0.14	0.35	0.150	0.068	800	360
12	0.11	0.28	0.092	0.042	500	230
14	0.09	0.23	0.055	0 025	350	160
16	0.07	0.18	0.032	0.015	200	90

* Hard drawn. † Soft. ‡ Soft: Extension, 0.12½. § Very hard. Comparison sample of Norway iron, very soft, broke at just one-half this figure.

Very soft and pure wire will have 20 or 25 per cent. less tenacity than is above given, while hard wire may give figures exceeding the above by an equal amount. In consequence of this variability it would be useless to express tenacities more precisely. *Turning iron down* has no important effect on the tenacity.

The considerable variations always observable in the general rate of increase of tenacity, which, other things being equal, accompanies reduction of size of wire, are due to the hardening of the wire in the draw-plate, and occasional restoration to its softest condition by annealing.

Beardslee has found the change of tenacity in forged and rolled bars, above noted, to be due to differences in amount of work done in the mill upon the iron. The extent of reduction of the pile sent to the rolls from the heating furnace is variable, its cross-sectional area being originally from 20 to 60 times that of the bar, the higher figure being that for the smallest bars. On making this reduction uniform, it is found that the tenacity of bars varies much less, in different sizes, and that the change becomes nearly uniform from end to end of the series of sizes, and becomes also very small in amount. By properly shaping the piles at the heating furnace, and by putting as much work on large as on small bars, it was found that a 2-inch (5.08 centimetres) bar could be given a strength superior by over 10 per cent., and a 4-inch (10.17 centimetres) could be made stronger by above 20 per cent. than iron of those sizes as usually made for the market. The surface of a bar is usually somewhat stronger than the interior.

The Limit of Elasticity will be found at from two-fifths the ultimate strength in soft, pure irons, to three-fifths in harder irons, and from three-fifths in the steels to nearly the ultimate strength with harder steels and cast irons. Barlow found good wrought iron to elongate one ten-thousandth its length per ton per square inch up to the limit at about 10 tons. The relation between the *series* of elastic limits, and the maximum resistance of the iron or the steel is well shown in strain-diagrams, which exhibit graphically the varying

relation of the stress applied to the strain produced by it throughout the process of breaking.

Experiments on Long Bars are seldom made, and but few are on record.

The following data were obtained from tests made for the Phœnix Iron Company:

TESTS OF LONG BARS OF WROUGHT IRON.

NUMBER OF BARS.	SIZE.	LENGTH.	STRETCH. INCHES.	MODULUS OF ELASTICITY. E
23	$3 \times \frac{7}{8}$	35′ 0″	.2587	32,470,000
24	$3\frac{1}{2} \times 1\frac{1}{4}$	35′ 0″	.2617	32,098,000
9	$4 \times 1\frac{3}{16}$	27′ 6″	.2033	32,464,700
24	$3\frac{1}{2} \times 1\frac{1}{4}$	35′ 0″	.2500	33,600,000
24	$3 \times \frac{3}{4}$	35′ 0″	.2633	31,902,000
12	$4 \times 1\frac{3}{4}$	35′ 0″	.2692	31,203,000
24	2×1	24′ $9\frac{1}{2}$″	.1948	30,544,000
36	$2\frac{7}{8}$″	11′ 9″	.0953	29,380,000
48	$2\frac{1}{2}$″	11′ 9″	.0955	20,319,000
68	$2\frac{3}{4}$″	11′ 11″	.0998	28,056,000
48	$2\frac{1}{4}$″	11′ 9″	.1008	27,777,777
72	$2\frac{3}{8}$″	11′ 9″	.0940	29,787,000
120	$2\frac{5}{8}$″	11′ 9″	.0947	29,567,000

Repeatedly Piling and Reworking improves the quality of wrought iron up to a limit at which injury is done by overworking and burning it. Clay's experiments on good fibrous puddled iron repiled, reheated, and reworked, resulted as shown in the table on next page.*

The iron thus treated exhibits increasing strength until it has been reheated five or six times, and then gradually loses tenacity at a rate which seems to be an accelerating one. Forging iron is similar in effect, and improves the metal up to a limit seldom reached in small masses.

The forging of large masses usually includes too often repeated piling and welding of smaller pieces, and it is thence

* Fairbairn, p. 249.

found difficult to secure soundness and strength. This is particularly the case where the forging is done with hammers of insufficient weight. The iron suffers, not only from reheating, but from the gradual loosening and weakening of the cohesion of the metal within the mass at depths at which the beneficial effect of the hammer is not felt.

EFFECT OF REHEATING.

NUMBER.	QUALITY.	TENACITY. *T*	
		Pounds per square inch.	Kilogrammes per square centimetre.
1	Puddled Bar.	43,904	3,086
2	Piled and reheated.	52,864	3,718
3	Repiled and reheated.	59,585	4,190
4	" " "	59,585	4,190
5	" " "	57,344	4,028
6	" " "	61,824	4,344
7	" " "	59,585	4,190
8	" " "	57,344	4,028
9	" " "	57,344	4,028
10	" " "	54,104	3,802
11	" " "	51,968	3,655
12	" " "	43,904	3,086

The effect of prolonged heating is sometimes seen in a granular, or even crystalline, structure of the iron, which indicates serious loss of tenacity. Large masses must always be made with great care, and used with caution and with a high factor of safety. Ingot iron is always to be preferred to welded masses of forged material for shafts of steamers and similar uses.

The Tenacity of Ingot Irons and Steels is less subject to variation by accidental modifications of structure and composition than is that of wrought iron. The steels are usually homogeneous and well worked, and are comparatively free from objectionable elements, their variation in quality being determined principally by the amount of carbon.

A singular uniformity of tenacity and of elastic limit is

observed within limited ranges of quality, with sudden changes at the limits of each range. On the whole, a gradual increase, both in tenacity and in elastic limit, is seen as the proportion of carbon is increased. The modulus of elasticity varies irregularly within a moderate range, and is evidently not affected by the proportion of carbon present. The quality of the metal is usually determined principally by the proportion of carbon, but is also affected, to a considerable extent, by the silicon and manganese, as well as by phosphorus.

The considerable variation here exhibited is partly due to the fact that these steels were supplied by several makers, who presumably used iron from different ores and adopted different mixtures in the crucible, and partly due to the varying hardness produced by accidental variation in rate of cooling, when delivered hot from the rolls.

The strength of good specimens of these metals, as they came from the mill, has been found by the Author to be, as a minimum, about

$$\left.\begin{aligned} T &= 60{,}000 + 70{,}000\,C \\ T_m &= 4{,}218 + 4{,}921\,C \end{aligned}\right\}$$

where T is the tenacity in pounds per square inch, and T_m in kilogrammes on the square centimetre;* C is the percentage of carbon. For annealed samples† of good ingot iron and steel,

$$\left.\begin{aligned} T &= 50{,}000 + 60{,}000\,C \\ T_m &= 3{,}515 + 4{,}218\,C \end{aligned}\right\}$$

Thus, as illustrating these cases, the Author has found the following figures by test:

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* *Trans. Amer. Soc. C. E.*, 1874.

† Structures in Iron and Steel; Weyrauch, translated by Dubois: N. Y., 1877.

TENACITY OF STEEL.

CARBON.	TENACITY. T			
	By Test.		By Calculation.	
Per cent.	Lbs. per square inch.	Kilogrammes per square centimetre.	Lbs. per square inch.	Kilogrammes per square centimetre.
0.53	79,062	5,558	81,740	5.746
0.65	93,404	6,566	88,940	6,153
0.80	99,538	6,997	98,060	6,893
0.87	106,979	7,520	102,020	7,171
1.01	109,209	7,677	110,300	7,754
1.09	116,394	8,183	113,480	7,978

The Author would adopt the above formulas to determine values to be inserted in specifications.

Bauschinger, experimenting upon Ternitz Bessemer steel, deduced the following:

$$\left.\begin{aligned} T_m &= 4{,}350\,(1 + C^2) \\ i.\,e.\ T &= 61{,}870\,(1 + C^2) \end{aligned}\right\}$$

which equation expresses the results of his tests with great accuracy.* American steels are seen to be slightly stronger than the European.

Weyrauch gives as a minimum set of values, such as may be used as a basis for specifications:

$$\left.\begin{aligned} T_m &= 3{,}700\,(1 + C) \\ i.\,e.,\ T &= 52{,}625\,(1 + C) \end{aligned}\right\}$$

which formula is probably also sufficiently exact as expressing the strength of good, pure iron and steel containing no appreciable quantity of the hardening elements other than carbon. For $C = 0$, $T = 52{,}625$ pounds per square inch

* "Versuche ueber die Festigkeit des Bessemerstahls," etc.

(3,700 kilogrammes per square centimetre), which is a usual figure for good bridge, cable, and blacksmith's iron of about 2 inches (5.08 centimetres) diameter.

As a general rule, the Elongations of Steel of the finest grades are diminished as the tenacity increases, and in steels tested for Trautwine* this reduction is nearly proportional to the increase in strength. Calling the shock-resisting power of the piece—or, more correctly, its work of resistance—equal to two-thirds the product of the ultimate resistance by the total elongation, its *total resilience*, R, we get

$$\left.\begin{aligned} R &= \tfrac{2}{3}\ T \times El = 4{,}000 \text{ foot-pounds nearly} \\ R_m &= \tfrac{2}{3}\ T_m \times El_m = 2.81 \text{ kilogrammetres} \end{aligned}\right\}$$

the first value being that for one square inch sectional area and one foot in length, the latter for one square centimetre area of cross-section and one centimetre in length. Then we have from the above:

$$\left.\begin{aligned} El &= \frac{6{,}000}{T} \\ El_m &= \frac{4.2}{T_m} \end{aligned}\right\}$$

for the elongation per inch or centimetre at the point of rupture.

This extension varies in crucible steels containing, as in the above examples, the usual proportion of manganese, from 10 per cent. at the lower limit to ½ per cent. at the higher. When care is taken to secure freedom from those elements which produce cold-shortness, higher values of elongation and resilience may be secured.

Makers of open-hearth steel have thus often been able to guarantee a tenacity of 80,000 pounds per square inch (5,624 kilogrammes per square centimetre), with an elongation of 20 per cent. and an elastic resistance of 50 per cent. of the

* Civil Engineer's Pocket Book.

ultimate. The total resilience of such metal is, therefore, about $\frac{2}{3} \times 80{,}000 \times .20 = 10{,}667$ foot-pounds per inch of section and foot of length, nearly 7.5 kilogrammetres for samples one square centimetre in section and a centimetre in length. At the elastic limit, the *elastic resilience* may be taken at about

$$R_e = \tfrac{1}{2}\, T_e \times El,$$

one-half the product of the elastic resistance by the elongation. This elongation is usually not far from one-tenth per cent., and the elastic limit rises from two-fifths in soft irons to nearly the ultimate resistance in hardened steel; for tool steels it may be taken at two-thirds, and for the softer grades usually at one-half.

By reducing the carbon and adding manganese some extraordinary metals are obtained. A "steel" containing 0.10 per cent. carbon and 0.45 per cent. manganese, has exhibited a tenacity of 90,000 pounds per square inch (6,327 kilogrammes per square centimetre) and an extension of 25 per cent.

The Elongation of Steel Bars may be reckoned at about three-fourths that of iron up to the elastic limit.

Boiler and Bridge Plate Steels, made by the pneumatic and open-hearth processes, have nearly the same strength as bars made by the same methods. The following are figures obtained by Hill* and the U. S. Board.

TENACITY OF O. H. BRIDGE PLATE—FRACTURED LENGTHWISE.

CARBON.	RESISTANCE ELASTIC.		RESISTANCE ULTIMATE. T		ELONGATION.
	Pounds per square inch.	Kilogrammes per square centimetre.	Pounds per square inch.	Kilogrammes per square centimetre.	
0.30	49,353	3,469	93,339	6,561	.16
0.40	63,227	4,444	86,410	6,074	.14
0.50	65,070	4,574	83,190	5,823	.10

* *Trans. Eng'r's. Soc. of West. Pennsylvania*, 1880.

SUMMARY OF TESTS OF TOOL STEELS.

STEEL.	WEIGHT CUT PER TOOL, IN POUNDS.				CHIPPING, SQUARE INCHES CUT PER TOOL.	RELATIVE VALUES.						TENSION. *T*	COMPRESSION. *C*	TORSION.			MEAN SPECIFIC GRAVITY.
	Turning.	Planing.	Slotting.	Drilling.		Turning.	Planing.	Slotting.	Drilling.	Chipping.	Total.	Breaking weight per square inch of original area.	Weight per square inch at first perceptible compression.	Proof-stress, in foot-pounds.	Ultimate stress, in foot-pounds.	Modulus of elasticity.	
A	7.5635	8.3887	1.2615	2.5693	3.56	.1819	.5133	.3415	.4387	.1479	.4020	108,194	44,162	95.01	297.34	.....	7 8132
B	17.9463	8.0951	2.3082	4.3800	9.166	.4315	.4953	.6249	.7478	.3809	.6638	100,975	47,567	95.60	287.86	.....	7.8054
C	14.8625	7.5274	3.2884	2.3779	4.76	.3573	.4606	.8902	.4060	.1978	.5725	92,524	43,303	105.25	270.29	.....	7.8058
D	21.5513	10.9897	3.5150	3.1030	5.768	.5181	.6724	.9516	.5298	.2397	.7211	112,704	44,737	100.57	284.29	.....	7.7737
E	26.1432	8.4000	1.6080	3.3270	1.741	.6286	.5139	.4353	.5680	.0723	.5493	111,457	42,913	93.06	320.09	.....	7.8030
F	20.8476	11.5835	3.1444	3.1000	24.063	.5012	.7087	.8512	.5203	1.0000	.8392	104,756	42,013	105.64	318.11	.....	7 8085
G	28.2031	9.7155	2.5139	2.8160	5.625	.6781	.5944	.6851	.4803	.2338	.6613	110,572	48,632	125.51	320.38	.....	7.8113
H	20.0742	13.7383	2.4370	3.8200	5.596	.4826	.8406	.6537	.6522	.2726	.7102	114,735	44,073	111.87	272.58	.....	7.8050
I	15.0859	8.3400	2.0569	3.4500	9.255	.3627	.5103	.5518	.5809	.3846	.5952	106,453	45.78	90.63	280.87	.....	7 8123
*J	32.5352	8.4795	3.6939	3.8000	7.708	.7822	.5 88	1.0000	.6488	.3293	.8099	109.440	42,098	102.27	316.03	.....	7.8118
K	25.7102	10.1665	2.7981	4.1230	4.688	.6181	.6221	.7575	.7037	.1948	.7173	91,625	46,343	102.92	292.74	.....	7.7894
L	21.0532	7.0620	2.0300	2.8500	4.938	.5062	.4872	.5405	.4806	.2052	.5534	95.414	48,601	99.71	271.81	.....	7.8015
†M	16.4927	5.8500	1.2367	4.2500	8.707	.3965	.3580	.3348	.7256	.3619	.5391	99.330	43,283	97.85	288.81	.....	7.8204
†N	13.4738	10.0880	2.1403	5.8570	11.5	.3239	.6272	.5794	1.0000	.4779	.7426	91,945	42,336	103.59	268.02	.....	7.8009
†O	15.6031	9.7340	2.3845	4.3700	6.688	.3751	.5956	.6455	.7461	.2779	.6539	91,875	41,054	90.10	272.08	.....	7.8239
*P	41.5914	26.3435	2.6412	5.6090	8.789	1.0000	1.0000	.7150	.9577	.3652	1.0000	115,922	46,358	103.55	322.78	.....	7.7733
*Q	9.6141	6.7090	1.2489	2.7120	8.625 / §19.7635	.2311	.4105	.3381	.4630	.3584 / §.8213	.4460 / §.5607	99,614	43,258	98.95	288.61	.....	7.8188
‡*Q	12.8343	.....	.....	.....	.....	.3086	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.8053

* Contributed by maker. † English Steel. ‡ Special bars. § Including actual work done by chisels partially worn.

CAST IRON.

TENSION, IN POUNDS.	COMPRESSION, IN POUNDS.		TORSION. SAMPLE ⅝″ × 1″.			MEAN SPECIFIC GRAVITY.
Breaking weight per square inch.	Weight per square inch at first perceptible compression.	Crushing weight per square inch.	Proof-stress, in foot-pounds.	Ultimate stress, in foot-pounds.	Modulus of elasticity.	
24,412	46,208	98,692	60.90	101.77	26,951,080	7.2115

MEAN TENACITY OF ORDNANCE CAST IRON.

CLASS.	SPECIFIC GRAVITY.	TENACITY. T		CARBON.	
		Lbs. per sq. in.	Kgs. per sq. cm.	Graphite.	Combined.
1	7.204	28,805	2,025	2.06	1.78
2	7.154	24,767	1,741	2.30	1.46
3	7.087	20,148	1,416	2.83	0.82

The best irons were generally richest in combined carbon and in manganese, and lowest in graphite, silicon, and phosphorus.

Iron supplied to the United States army must be of uniform tenacity, should have a strength of 25,000 to 30,000 pounds per square inch (1,758 to 2,190 kilogrammes per square centimetre), and a specific gravity of about 7.245. *Good* gun iron is expected to range from 30,000 to 32,000 pounds per square inch (2,190 to 2,250 kilogrammes per square centimetre). Good car-wheel irons often exhibit nearly the tenacity of gun iron, and sometimes elongate three-fourths of 1 per cent. at fracture. Ordinary irons have a tenacity of about 20,000 pounds (1,406 kilogrammes), and often stretch less than 0.1 per cent. Dark irons, as No. 2, of good makes, have a tenacity equal to about two-thirds that of No. 4 of the same make, a good iron giving, in experiments by the Author,* 20,500 and 34,407 pounds per square inch (1,441 and 2,419 kilogrammes per square centimetre) respectively. These samples passed the elastic limit at 7,333 and 12,000 pounds per square inch (515 and 844 kilogrammes per square centimetre), and their moduli of elasticity were 11½ and 16 millions (nearly) pounds per square inch (8,045 to 11,248 kilogrammes per square centimetre). Their densities were 7.186 and 7.259. The average of a large number of tests of iron of all grades, but usually No. 3 machinery iron, is, in

* Report on Salisbury Irons, *R. R. Gazette*, 1877. Pamphlet, 1878.

tension, 18,800 pounds per square inch, as obtained by the Author, while Hodgkinson quotes, for English cast irons, about 16,000 (1,222 and 1,125 kilogrammes per square centimetre). The following may be taken as figures which should be given by the best sorts of cast irons:

TENACITY OF GOOD CAST IRONS.

KIND.	TENACITY. T		SPECIFIC GRAVITY.
	Lbs. per sq. in.	Kgs. per sq. cm.	
Good pig iron.....	20,000	1,406	7.10
Tough cast iron	25,000	1,758	7.22
Hard cast iron	30,000	2,109	7.28
Good tough gun iron.....	30,000	2,109	7.25

It will usually be found that the best single index of the strength of cast iron is its density; and the best machinery and good gun irons should, in small castings, have a tenacity of about

$$\left.\begin{aligned} T &= 25{,}000(D-7) + 20{,}000 \\ T_m &= 1{,}758(D-7) + 1{,}406 \end{aligned}\right\}$$

between the limits of density, $D = 7$; $D = 7.28$.

In heavy masses the strength of cast iron may be very seriously reduced, and usually is diminished appreciably, by the internal strains due to shrinkage, and by lessened specific gravity. Even in such small variations of section as Hodgkinson experimented upon—1, 2, and 3-inch sections—this loss of strength was very great; the relative tenacities were as 100, 80, and 77, in test pieces from sample-bars such as are furnished under specification. James, repeating the experiment, obtained the figures 100, 66, and 60. The surface of a casting is usually, but not always, stronger than the interior of the mass.

The strength of cast iron of the usual foundry grades is generally increased by remelting, partly in consequence of the loss of carbon, and also, possibly, by the refining which occurs during the process. This change was noted by Wade when remelting No. 1 pig iron. Thus:

TENACITY OF REMELTED CAST IRON.

	SPECIFIC GRAVITY.	TENACITY. T	
		Lbs. per sq. in.	Kgs. per sq. cm.
First melting	7.032	14,000	984
Second melting	7.086	22,900	1,610
Third melting	7.198	30.229	2,207
Fourth melting	7.301	35,786	2,516

The same effect is produced by prolonged exposure to the flame of the reverberatory furnace, thus:

TENACITY OF CAST IRON.

TIME OF FUSION.	TENACITY. T	
	Lbs. per sq. in.	Kgs. per sq. cm.
½ hour	17,843	1,254
1 hour	20,127	1,415
1½ hours	24,387	1,714
2 hours	34,496	2,425

Bramwell increased the strength of dark grades of cast iron more than 250 per cent. by four hours' fusion. In Fairbairn's experiments No. 3 iron was melted eighteen times, and a maximum increase of 220 per cent. was observed at the fourteenth melting.

Strain Diagrams of Cast Iron.—The accompanying diagram is the graphical representation of experiments made upon Salisbury cast iron referred to above. It is seen that such metal gives a parabolic strain diagram, and has no definite elastic limit. The Author has been accustomed to assume that the elastic limit may be taken at that point at which a

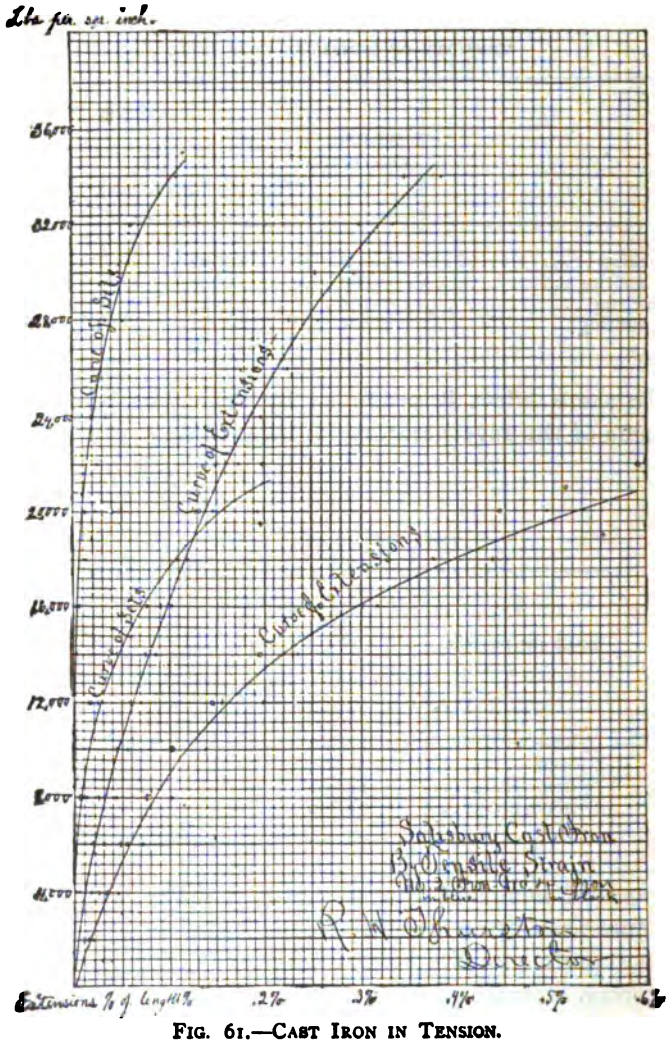

FIG. 61.—CAST IRON IN TENSION.

tangent to the curve makes an angle of 45° with the axes. This is fairly accurate for the harder varieties of iron, and, although less exact for softer irons, leads to no serious error.

Stays.—Where flat surfaces are secured against lateral pressure by stay-bolts, as is done in steam boilers, these bolts may yield either by breaking across, or by shearing the threads of the screw in the bolt or in the sheet. Such bolts should not be so proportioned that they are equally liable to break by either method, but should be given a large factor of safety (15 to 20) to allow for reduction of size by corrosion, from which kind of deterioration they are liable to suffer seriously. Wrought iron and soft steels are used for these bolts. They are secured through the plate, and the projecting ends are usually headed like rivets. Nuts are sometimes screwed on them instead of riveting them when they are not liable to injury by flame.

"Button-set" heads are from 25 to 35 stronger than the conical hammered head, and nuts give still greater strength.

Experiments made by Chief Engineers Sprague and Tower, for the U. S. Navy Department, lead to the following formula* and values of the coefficient a, p being the safe working pressure, t the thickness of plate, and d the distance from bolt to bolt:

$$p = a\frac{t^2}{d^2}$$

VALUES OF a IN BRITISH AND METRIC MEASURES.

	A.	A_m.
For iron plates and bolts	24,000	1,693
For steel plates and iron bolts	25,000	1,758
For steel plates and steel bolts	28,000	1,968
For iron plates and iron bolts with nuts	40,000	2,812
For copper plates and iron bolts	14,500	1,020

The working load is given in pounds on the square inch and kilogrammes per square centimetre, the measurements being taken in inches and centimetres. The heads, where riveted, are assumed to be made of the button shape.

* *Report on Boiler Bracing*; Washington, 1879.

The diameter of stay is made about $2\sqrt{t}$, the number of threads per inch 12, or 14 (5 or 6 per centimetre). A very high factor of safety, as above, is recommended for stays, to afford ample margin for loss by corrosion.

Lloyd's Rule for stayed plates is

$$p = \frac{a t_1^2}{p_1^2}$$

in which p is the working pressure in pounds on the square inch, t_1 the thickness of plate in sixteenths of an inch, and p_1 is the distance apart of the stays in inches.

The coefficient a has the following value:

$a = 90$ for plate $\frac{7}{16}$ inch thick or less; with screw stays and riveted heads;
$a = 100$ for plate $\frac{7}{16}$ inch thick or more; screw stays and riveted heads;
$a = 110$ for plate $\frac{7}{16}$ inch thick or less; screw stays and nuts;
$a = 120$ for plate $\frac{7}{16}$ inch thick or more; screw stays and nuts;
$a = 140$ for plate $\frac{7}{16}$ inch thick or more; screw stays with double nuts;
$a = 160$ for plate $\frac{7}{16}$ inch thick; with screw stays, double nuts and washers.

The Board of Trade of Great Britain prescribes,

$$p = \frac{a (t_1 + 1)^2}{s - 6}$$

in which t_1 is the thickness of plate as above, and s is the area of surface supported, in square inches.

$a = 100$ for plates not exposed to heat, and fitted with nuts and washers of 3″ diameter and of $\frac{3}{5}$ the thickness of the plates;
$a = 90$ for same case, but with nuts only;

$a = 60$ where exposed to steam, and fitted with nuts and washers;
$a = 54$ for same case, with nuts only;
$a = 80$ where in contact with water; with screw-stays and nuts;
$a = 60$ for latter case, and screw-stays riveted;
$a = 36$ for plates exposed to steam, screw-stays riveted.

Where girder-stays are used,

$$p = \frac{a d_1^2 t_1^2}{(w - p_1) d_2 l}$$

in which expression, d_1, t_1 are the depth and thickness of the girder, p_1 is the pitch of bolts carrying the girder; d_2 is the distance between girders; w is the width of crown; l is the length of girder. Where one, two or three, and where four bolts, respectively, carry the girder, $a = 500$, 750, and 850.

Mr. D. K. Clark,* comparing data obtained experimentally with his own formulas for stayed surfaces, gives the following as safe values:

Deflection to the elastic limit,

$$d = \frac{d_1}{44}$$

where d is the "rise" of the arch, or the deflection, and d_1 the "pitch" of the stays.

Maximum pressure,

$$p = 407 \frac{tT}{d_1}$$

when t is the thickness and T the tenacity.

Elastic resistance,

$$\text{For iron, } p = 5{,}000 \frac{t}{d}$$

$$\text{For steel, } p = 5{,}700 \frac{t}{d}$$

* *Inst. C. E.*, 1877–78, Vol. LIII., abstracts.

It is assumed that the stay-bolts are so secured that the distortion of the plate cannot break them out. The stay-bolt is equally likely to shear and to break in tension when its diameter is twice the thickness of the plate. It should, however, be made a quarter inch larger to allow for corrosion, which is more dangerous on the stay than on the sheet.

Cylindrical Boiler-Shells, and other thin cylinders, have a thickness which is determined by the tenacity of the metal and the character of the riveted or other seam. If p be the internal pressure, T the mean tenacity to be calculated upon along the weakest seam, r the semidiameter, and t the thickness, we have for axial stresses for equilibrium:

$$p\pi r^2 = 2\pi r t T,$$

and

$$t = \frac{pr}{2T}$$

But for transverse stresses tending to rupture longitudinal seams,

$$pr = tT,$$

and

$$t = \frac{pr}{T}$$

With seams of equal strength in both directions, therefore, the cylinder is at the point of rupture along the longitudinal seams, while capable of bearing twice the pressure on girth seams. It is evident that spheres have twice the strength of cylinders of equal diameter.

Thick cylinders are considered in article 248, as they are usually made in cast iron.

Flat Boiler Heads are made both in wrought and cast iron. For these Clark's rules may be used.*

For elastic deflection,

$$d = \frac{d_1}{44}$$

* *Inst. C. E.*, Vol. LIII., Abstracts: London, 1877–78.

For maximum pressure,

$$p = 0.215 \frac{tT}{d_1}$$

or, for iron,

$$p = 10{,}000 \frac{t}{d_1}$$

For steel,

$$p = 11{,}500 \frac{t}{d_1}$$

For cast iron,

$$p = 4{,}000 \frac{t}{d_1}$$

when t is the thickness, d_1 the diameter, and T the tenacity.

For spherical ends,

$$p = \frac{at}{\frac{d_1^2}{4v + v}}$$

where a is 108,000 for wrought iron, 125,000 for steel, 45,000 for cast iron, and v is the versed sine or rise of the head.

Lloyd's Rule for cylindrical shells of boilers is

$$p = \frac{abt}{d}$$

in which a is 155 to 200 for iron, 200 to 250 for steel, b per cent. of strength of solid sheet retained at the joint, t is the thickness of the plate, and d the diameter of the shell. The value of b is thus reckoned (n = number of rows of rivets):

$$b = 100 \frac{p_1 - d_1}{p_1}, \text{ for the plate;}$$

$$b = 100 \frac{na_1}{p_1 t}, \text{ for rivets in punched holes;}$$

$$b = 90 \frac{na_1}{p_1 t}, \text{ for rivets in drilled holes;}$$

where p_1 is the pitch of rivets; d_1 is their diameter; a_1 is the area of the rivet-section. When in double-shear, $1.75a_1$ is taken for a_1. The factor of safety is taken at 6, and boilers are tested by water-pressure up to $2p$.

The iron is expected to have a tenacity of at least 21 tons per square inch; steel must bear 26 tons (3,307 to 4,095 kilogs. per sq. cm.).

Welds are found, when well made, to carry 75 to 85 per cent. of the sheet.

Steam-pipe is usually made with an enormous excess of strength, to meet accidental stresses, such as those due to motion of water within them. The Author has tested pipe broken by "water-hammer," as the engineer calls it, to 1,000 pounds per square inch (70 kilogrammes per sq. cm.) *after* it had been thus cracked in regular work in a long line, while the steam pressure was less than 100 pounds (7 kilogs. per sq. cm.). They had all been previously tested to about one-third this pressure.

Strength of Cast-Iron Cylinders.—Cylinders for steam engines are usually given a thickness greatly in excess of that demanded to safely resist the steam pressure; often, according to Haswell,

$$t = \frac{dp}{2500} + \frac{1}{8}$$

for vertical cylinders, where d is the internal diameter, and

$$t = \frac{dp}{2000} + \frac{1}{8}$$

for horizontal cylinders of considerable size.

In metric measures, kilogrammes and centimetres, these formulas become

$$t = \frac{dp}{200} + \frac{1}{3}, \text{ nearly}$$

$$t = \frac{dp}{160} + \frac{1}{3}, \text{ nearly}$$

If r_1 is the external, and r_2 the internal radius, T the tenacity of the metal, t its thickness, and p the intensity of the internal pressure, we have, for the *thin cylinder*, as an equation for equilibrium:

$$pr_2 = T(r_1 - r_2) = Tt, \text{ nearly}$$

and

$$r_2 = \frac{Tt}{p}$$

$$t = r_1 - r_2 = \frac{pr_2}{T}$$

$$p = \frac{Tt}{r_2}$$

For the *thick cylinder*, however, the resistance at any internal annulus of the cylinder is less than T.

Thick Cylinders, technically so called, are those which are of such thickness that the mean resistance falls considerably below the full tenacity of the metal, as exhibited in thin cylinders, in low-pressure steam boiler shells, for example. Such cylinders are seen in the "hydraulic" press, and in ordnance.

*Barlow** assumes the area of section unchanged by stress, although the annulus is thinned somewhat by linear extension. If this is the fact, as the tension on any elementary ring must vary as the extension of the ring within the elastic limit, the stress in such element will be proportional to the reciprocal of the square of its radius, *i.e.*, it will be

$$p \propto \frac{1}{r^2}$$

and, taking the total resistance as $p'r_1$, when p' is the internal

* *Strength of Materials*, 1867, p. 118.

fluid pressure, since the maximum stress at the inner radius is T, that on the inner elementary annulus is Tdx, and on any other annulus $\frac{Tr_2^2}{x^2}dx$; while the total resistance will be, on either side the cylinder,

$$p_1 r_2 = Tr_2^2 \int_{r_2}^{r_1} \frac{dx}{x^2} = T\frac{r_2(r_1 - r_2)}{r_2 + (r_1 - r_2)} = T\frac{r_2 t}{r_2 + t}$$

The maximum stress is at the interior, and may be equal, as taken above, to the tenacity, T, of the metal; then

$$T = \frac{p_1 r_1}{t} = \frac{p_1(r_2 + t)}{t}$$

and the thickness

$$t = \frac{p_1 r_2}{T - p_1}$$

while the ratio of the radii

$$\frac{r_1}{r_2} = \frac{Tt}{p_1} \div \frac{t(T - p_1)}{p_1} = \frac{T}{T - p_1}$$

Lamé's Formula, which is more generally accepted, and which is adopted by Rankine, gives smaller and more exact values than that of Barlow. In the above, no allowance is made for the compressive action of the internal expanding force upon the metal of the ring. The effect of the latter action is to make the intensity of pressure at any ring less than before by a constant quantity,

$$p \propto \frac{a}{r^2} - b,$$

and the tension by which the ring resists that pressure greater,

$$p' \propto \frac{a}{r^2} + b.$$

When $r = r_1$, $p = 0$; when $r = r_2$, $p = p_1$;

$$\text{then } p_1 = \frac{a}{r_2^2} - b, \text{ and } 0 = \frac{a}{r_1^2} - b,$$

$$a = p_1 \frac{r_1^2 r_2^2}{r_1^2 - r_2^2}; \quad b = p_1 \frac{r_2^2}{r_1^2 - r_2^2};$$

and the maximum possible stress on the inner ring is

$$T = \frac{a}{r_2^2} + b;$$

$$= p_1 \left(\frac{r_1^2}{r_1^2 - r_2^2} + \frac{r_2^2}{r_1^2 - r_2^2} \right).$$

$$T = p_1 \frac{r_1^2 + r_2^2}{r_1^2 - r_2^2}$$

$$p_1 = T \frac{r_1^2 - r_2^2}{r_1^2 + r_2^2}$$

and the ratio of inner and outer radii is

$$\frac{r_1}{r_2} = \sqrt{\frac{T + p_1}{T - p_1}}$$

Of these two formulas, the first gives the larger and consequently safer results, and, in the absence of certain knowledge of the distribution of pressure within the walls of the cylinder, is perhaps best.

For thick spheres, Lamé's formula becomes

$$p_1 = T \frac{2 (r_1^3 - r_2^3)}{r_1^3 - 2 r_2^3}$$

$$\frac{r_1}{r_2} = \sqrt[2]{\frac{2(T+p_1)}{2T-p_1}}$$

Clark's formula* is more recent than the preceding. It is assumed that the expansion of concentric rings into which the cylinder may be conceived to be divided is inversely as their radii, and that the curve of stress will become parabolic if so laid down that the radii shall be taken as abscissas and the stresses as ordinates, the total resistance thus varying as the logarithm of the ratio of the radii. Then if the elastic limit be coincident with the ultimate strength, and

T = the tenacity of the metal;
R = the ratio, external diameter divided by internal;
p = the bursting pressure;

$$p = T \times \text{hyp log } R$$

$$R = e^{\frac{p}{T}}$$

In other cases, instead of T take the value of the resistance at the elastic limit, and base the calculation of proportions upon the elastic limit and its appropriate factor of safety. The formulas as given are considered applicable to cast iron.

The strength of thick cast cylinders with heads cast in, may, however, sometimes be far in excess even of the calculated resistance of thin cylinders. This is shown by data obtained by test of cast iron (gun metal) cylinders made at the Watertown Arsenal, by Colonel T. T. S. Laidley, U. S. army. These cylinders were eight in number, 11 inches (27.9 centimetres) in diameter, and 22½ inches (57 centimetres) long, bored out and lined with a thin copper or bronze tube or an iron cylinder and turned on the outside; they were, in fact, small lined guns. All proved to be stronger than calculated as above.

* *Rules and Tables*, p. 687.

Cast Iron has a power of resisting compression, which, as with other metals, may be taken within the elastic limit, or within the range of distortion and stress usual in application, as following the same law as resistance to extension. Its absolute value increases with the proportion of carbon, phosphorus, manganese, and silicon, in combination up to some undetermined limit, and decreases as the proportion is increased of graphitic carbon, of silicon, and other weakening substances. Sound castings will have maximum resistance to compression at a density not far from, though a little above, that which gives maximum tenacity. In general, specifications for cast iron under pressure should be similar in form to those framed for the same iron in tension. The iron should usually be No. 3 iron for ordinary work, and should have a density of 7.26 or 7.28.

The following figures are from the mean of a large number of tests of iron intended for ordnance:

RESISTANCE TO COMPRESSION—CAST IRON.

NUMBER.	SPECIFIC GRAVITY.	RESISTANCE. *C*		TENACITY.	
		Lbs. on sq. in.	Kilogs. on sq. cm.	Lbs. on sq. in.	Kilogs. on sq. cm.
1	7.087	99,770	7,014	20,877	1,468
2	7.182	139,834	9,830	30,670	2,171
3	7.246	158,018	11,118	35,633	2,505
4	7 270	159,930	11,253	39,508	2,777
5	7.340	167,037	11,743	32,458	2,282

The tenacities are presented for comparison, and the table so completed will enable all to be compared with the chemical composition and density of irons of similar tenacity as already given.

Tests of cast iron of similar grade to those reported pages

375, 378, as made by the Author in tension, gave the following results:

COMPRESSION AND DUCTILITY OF CAST IRON.

NUMBER.	RESISTANCE. C		TOTAL COMPRESSION.
	Lbs. on sq. in.	Kilogs. on sq. cm.	Per cent.
No. 2 iron	81,488	5,699	9.48
" "	89,127	6,265	8.72
" "	91,674	6,445	5.85
No. 4 "	127,323	8,951	9.95
" "	127,323	8,951	9.50

The formula proposed by Hodgkinson for the rather weak cast iron used in his experiments is the following:

$$\left.\begin{aligned} P &= 170{,}763e - 36{,}318e^2 \\ P_m &= 12{,}004e - 2{,}553e^2 \end{aligned}\right\}$$

in which P and P_m are the loads in British and metric measures respectively, and e the corresponding elongation up to a limit which is rarely as high as one per cent., and is usually not far from the point of rupture.

Strain Diagrams of Cast Iron in Compression.—The accompanying figure contains the strain diagrams illustrating the experiments of the table. The elastic limit may be taken at one-half the ultimate resistance, although it cannot be definitely determined, since, as is best shown by the strain diagrams, the change in rate of distortion is too gradual to permit its identification. It is evident that the strain diagrams of iron and steel under compression have equations similar to that proposed for those of metal under tension. The stronger and stiffer sample is No. 4, and the weaker and more ductile is No. 2 iron. The small circles are the observations of extension and load; the crosses indicate corresponding sets.

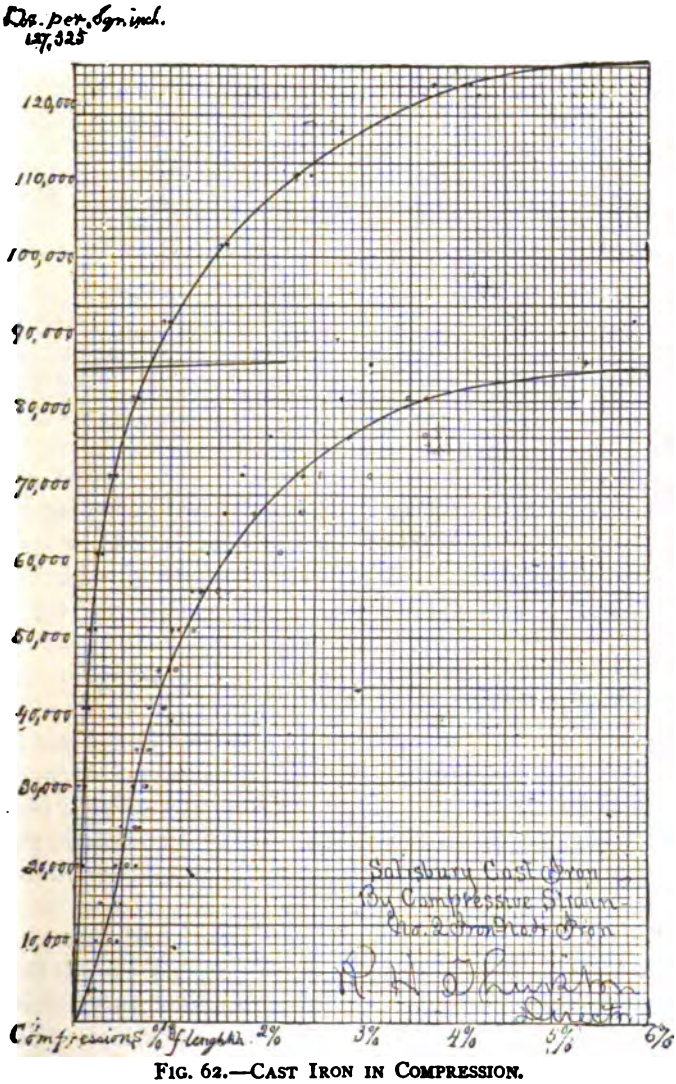

FIG. 62.—CAST IRON IN COMPRESSION.

Long Bars in Compression.—The following are the results obtained by Hodgkinson, testing cast-iron bars 10 feet (3.04 metres) long and of 1 inch (2.54 centimetres) area of section:

RESISTANCE TO COMPRESSION, AND ELASTICITY OF CAST-IRON BARS.

LOAD. C		COMPRESSION.		MOD. ELASTICITY.	
Lbs. per sq. in.	Kgs. per sq. cm.	Total. e	Permanent.	Lbs. per sq. in.	Kgs. per sq. m.
2,064.74	145.1	.0001561	.00000391	13,231,300	$9,293 \times 10^6$
6,194.24	439.3	.0004981	.00003331	12,442,300	$8,744 \times 10^6$
10,323.73	725.5	.00082866	.00007053	12,467,100	$8,761 \times 10^6$
14,453.22	1,015.5	.00128025	.00011700	12,253,700	$8,612 \times 10^6$
18,582.71	1,305.9	.00154218	.00017085	12,058,100	$8,474 \times 10^6$
24,776.95	1,741.3	.00208016	.00036810	11,920,000	$8,377 \times 10^6$
33,030.8	2,326.7	.0029450	.00050768	11,222,750	$7,887 \times 10^6$

Wrought Iron in Compression.—The British "Steel Committee" tested iron and steel by compression in 1868–70, and found the elastic resistance of English wrought iron to lie between 10 and 14 tons per square inch, averaging about 12, or nearly 26,000 pounds per square inch (1,827.8 kilogrammes on the square centimetre), and an extension, to the elastic limit, of 0.097 per cent. (0.001 nearly).

Experimenting on steels, this committee found the elastic limit, in compression, at 50,000 pounds per square inch, nearly (3,515 kilogrammes per square centimetre), and at a percentage of compression ranging from 0.000065 to 0.000080 per ton per square inch, and a total of usually not far from 0.0018, without regard to kind of steel.

Kirkaldy, experimenting on the softer and purer iron of Sweden, obtained an average of about 25,000 pounds (1,757.5 kilogrammes on the square centimetre), and an ultimate resistance of nearly 175,000 pounds per square inch, with a 1-inch cube (12,300 kilogrammes on the square centimetre), and about one half that amount on a 1½-inch (3.82 centimetres) bar 2 diameters long. Ten diameters' length reduced the figures to about 15 per cent. of the maximum. The compression was nearly 50 per cent.

Tangye found the resistance of small areas of larger

masses under compression to be sensibly overcome at about 50,000 pounds per square inch, and a deep indentation to be produced by double that load (3,515 and 7,030 kilogrammes per square centimetre).

Flues and Cylinders subjected to external pressure resist that pressure in proportion to their stiffness and their compressive strength if thin, and if thick sustain a pressure proportional to their thickness and maximum resistance to crushing.

Fairbairn,* experimenting on flues of thin iron, 0.04 inch (0.102 centimetre), of small diameter, 4 inches (10.2 centimetres) to 12 (31 centimetres), and from 20 inches (50.8 centimetres) to 5 feet (1.52 metres) long, found that their resistance to collapse varied inversely as the product of their lengths and their diameters, and directly as the 2.19 power of their thickness.

The following equation fairly expressed his results when p is the external pressure in pounds per square inch, t their thickness in inches, and d their diameter. L is the length in feet:

$$t = \sqrt[2.19]{\frac{pdL}{806{,}000}}; \; p = 806{,}000\,\frac{t^{2.19}}{dL}.$$

or, for the length in inches,

$$p = 9{,}672{,}000\,\frac{t^{2.19}}{dl}$$

In metric measures, kilogrammes and centimetres diameter, and metres of length,

$$p = 68{,}000\,\frac{t^{2.19}}{dL}, \text{ nearly}$$

$$t = \sqrt[2.19]{\frac{pdL}{68{,}000}}$$

* *Useful Information.* Second Series.

For elliptical flues take $d = \frac{2a^2}{b}$; where a is the greater and b the lesser semi-axis.

These equations probably give too small values of t for heavy flues under high pressure.

Belpaire's rule, deduced from Fairbairn's experiments, is,

$$p = 1{,}057{,}180 \frac{t^{2.081}}{l^{0.654} d^{0.889}}$$

Lloyd's rule for flues is, for working pressures,

$$p = \frac{at^2}{Ld}$$

in which a is made 89,600 pounds per square inch.

The *British Board of Trade rule* is, for cylindrical furnaces with butted joints,

$$p = \frac{at^2}{(L + 1)d}$$

in which a is 90,000, provided, always,

$$p < 8{,}000 \frac{t}{d}.$$

For large joints $a = 70{,}000$ unless beveled to a true circle, when $a = 80{,}000$. If the work is not of the best quality, these values of a are reduced to 80,000, 60,000, and 70,000.

The factor of safety in boiler work should not be allowed to fall below 6. "Corrugated" flues are claimed to have double the strength and much greater elasticity than "plain" flues.

Resistance of Columns, Posts, or Struts.—The resistance of parts of structures under compression is often determined largely by their form and by the method of putting them together or of building them up. In construction

such parts are called pillars, posts, or struts, and are given all the various forms shown in the accompanying figures:

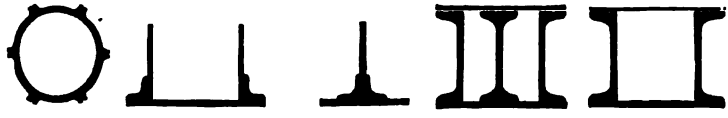

FIG. 63.—CROSS SECTIONS OF COLUMNS.

Their ends are usually fitted with bases or "shoes" of cast or forged iron, having, in accepted practice, a minimum thickness of

$$t = \frac{P}{12{,}000d};$$

where P is the total load in pounds, and d the diameter in inches of the pin sustaining the strut, as is common in American bridge construction. The first of the forms here shown is known as the "Phœnix" column. In all such pieces the resistance to compression is less than the figures already given for short pieces yielding by actual crushing.

Flexure of Columns.—It is shown, in works on the theory of the strength of materials, that the general equation for flexure of any piece subjected only to stress producing bending is, when I is the principal moment of inertia,*

$$EI\frac{d^2y}{dx^2} = -Py$$

the second member being negative when, as in the bending of very long columns, the moment of the flexing force is negative with respect to the moment of the resisting forces, y being the ordinate of any point in the curved axis, and x the abscissa, as the curve of the beam is concave to the axis of x. From this expression is derived, by Euler and later

* Discovered, and proven, by Prof. Robinson to be the principal moment for all cases. *Vide Strength of Wrought Iron Bridge Members; Van Nostrand's Science Series*, No. 60, equation (5).

authors, an equation for the load on a column, when both ends are rounded or pinned, thus:

The integral of equation 74 is,

$$y = a \sin \frac{x}{\sqrt{\frac{EI}{P}}};$$

but to make $y = 0$ at the extremities of the column, when $x = l$, we must have

$$\frac{l}{\sqrt{\frac{EI}{P}}} = \pi,$$

or equal some multiple of π; thence we may put,

$$\frac{l}{\pi} = \sqrt{\frac{EI}{P}},$$

and, therefore,

$$P = \frac{\pi^2}{l^2} EI = 10 \frac{EI}{l^2}, \text{ nearly}$$

in which l is the length, E the modulus of elasticity, P the load, and I the moment of inertia of the transverse section.

Strength of Columns of Great Length.—Since this resistance is independent of the extent of flexure, it is evident that, passing the limit of elasticity, where the law of variation of resistance changes, as will be seen by studying strain diagrams given later, the formula gives the breaking load, when, as in the case here taken, there is no external force aiding the column in the effort to retain its form. This expression is proposed by Navier* for columns 20 diameters or more in length. Later writers would restrict it to still more slender columns—30 to 40 diameters.

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* *Resumé des Leçons*: Paris, 1838, p. 204.

When the column is cylindrical, the equation becomes,

$$P = \frac{1}{64}\pi^3 E\frac{d^4}{l^2} = \frac{1}{2}E\frac{d^4}{l^2}, \text{ nearly}$$

and for square columns,

$$P = \frac{1}{12}\pi^2 E\frac{b^4}{l^2} = \frac{5}{6}E\frac{b^4}{l^2}, \text{ nearly}$$

This equation may be used for flat-ended columns 60 or 70 diameters long by multiplying the second member by 4, and to columns having one end flat, the other rounded, when 40 or 50 diameters long, by making the factor 2;* making the general equation,

$$P = 40\frac{EI}{l^2}, \text{ nearly}$$

and

$$P = 20\frac{EI}{l^2}, \text{ nearly}$$

While the equations become for cylinders,

$$P = 2E\frac{d^4}{l^2}$$

$$P = E\frac{d^4}{l^2}$$

and for square pillars,

$$P = 3\tfrac{1}{3}E\frac{b^4}{l^2}$$

$$P = 1\tfrac{2}{3}E\frac{b^4}{l^2}$$

Hodgkinson's simple formula for the same column is given:

For long columns, fixed, solid,

Cast iron, $P = 49.4\frac{d^{3.55}}{L^{1.7}}$

* *See Strength of Bridge Members*, Robinson: New York, D. Van Nostrand, 1882, p. 107.

$$\text{Wrought iron, } P = 149.7\,\frac{d^{3.55}}{L^{1.7}}$$

For hollow columns,

$$\text{Cast iron, } P = 49.6\,\frac{d_1^{3.55} - d^{3.55}}{L^{1.7}}$$

the diameter being taken in inches, the length in feet, and the load in tons.

Standard Formulas for Strength of Columns.—In all ordinary cases of yielding of columns, and in all cases of short columns, even with rounded ends, the lateral resistances must be considered. For such cases, engineers are accustomed to use what is generally known as Gordon's formula—more properly called Tredgold's*—or a modification of wider application proposed by Rankine.†

Tredgold's formula is the following:

$$P = \frac{Cbd}{1 + a\left(\frac{l}{d}\right)^2}.$$

for rectangular columns. The values of a and C for rupture, are given later. Working loads are usually restricted to $C = 7{,}500$, or $C = 8{,}500$, for ordinary and Phœnix sections respectively, and $a = \frac{1}{16{,}000}$ for pin connections to $a = \frac{1}{50{,}000}$ for flat ends.

This formula applies to pillars with rounded ends.

Gordon obtained constants for this formula from various sources, and it has become more generally known by his name. The following are the constants obtained from hollow columns for the modified formula, for fixed ends:

$$P = \frac{CK}{1 + a\left(\frac{l}{d}\right)^2}$$

* *Tredgold on Strength of Cast Iron*, second edition, p. 183.

† *Applied Mechanics*, p. 305.

MATERIAL.	SECTION.	C.		a.
		Lbs. per sq. in.	Kilogs. per sq. cm.	
Cast iron	Circle.	80,000	5,624	0.0025
Cast iron	Square.	80,000	5,624	0.002
Wrought iron	Circle.	36,000	2,628	0.00033
Wrought iron	Square.	36,000	2,628	0.00017

C is the maximum resistance to crushing.

For rounded ends, or pin-connections, multiply a by 4, and for one end fixed, by 2.

In Gordon's formula, the load is in pounds the area, K, in square inches, and the length and diameter in the same units. All the values of C are lower than it is now customary to take them.

Rankine's formula is of more general application than Tredgold's, although derived by a similar process. It has the following form for a strut fixed at both ends :*

$$P = \frac{CK}{1 + a\left(\frac{l}{k}\right)^2}$$

in which P is the load, C the resistance to crushing in short pieces, both in the same terms, K the sectional area, l and k the length of the column, and the least radius of gyration of its cross section in the same units. For rounded ends, a is multiplied by 4, and for one end fixed, by $\frac{1}{9}$. The following are values of C and a as given by Rankine :

	C.		a.
	Lbs. on sq. in.	Kilogs. on sq. cm.	
Cast iron	80,000	5,624	$\frac{1}{6400}$
Wrought iron	36,000	2,628	$\frac{1}{36000}$

* *Rules and Tables*, p. 210.

The formula of Tredgold and its modifications may be thus derived:

If the load on the head of a column be P, the intensity of the stress due that load, at any section, K, is

$$p' = \frac{P}{K}$$

and this is, as a maximum in short pieces and masses, equal to the resistance, C, to crushing given in the preceding tables.

But when a long pillar or column yields, it does so by bending transversely, and follows the law already given in connection with the deduction of Euler's formula. This brings a stress, p'', due to bending solely, upon parts already strained by the stress, p', producing a maximum,

$$p' + p'' = C$$

The value of p'' varies directly as the moment and inversely as the breadth and the square of the thickness of a rectangular section,* or as the cube of the diameter for a circular section of column, and if M is the bending moment of the load for a square section,

$$C = p' + p'' = \frac{P}{K} + a\frac{M}{bd^2}$$

and since the maximum allowable deflection is proportional to the square of the length divided by the thickness,

$$C = \frac{P}{K} + aP\frac{l^2}{bd^3}$$

$$= \frac{P}{K}\left[1 + a\left(\frac{l}{d}\right)^3\right]$$

* Rankine; *Applied Mechanics*, p. 305.

and the crushing load is

$$P = \frac{CK}{1 + a\left(\frac{l}{d}\right)^2}$$

while the maximum intensity of pressure will be

$$p = \frac{P}{K} = \frac{C}{1 + a\left(\frac{l}{d}\right)^2}$$

the values of which are always less than C, and decrease as the column is lengthened, finally becoming identical with that obtained with Euler's method.

It is evident that the same formula, with suitable alteration of the constant, a, may be written, as by Rankine.

The following are values of k^2 for solid sections and for hollow sections with thin sides:

VALUES OF RADII OF GYRATION.

Form of Section.	k^2.
Solid; rectangle	$\frac{1}{12}\,h^2$.
Thin; square	$\frac{1}{6}\,h^2$.
Thin; rectangle	$\frac{h^2}{12} \cdot \frac{h + 3b}{h + b}$
Solid; cylinder	$\frac{1}{16}\,h^2$.
Thin; cylinder	$\frac{1}{8}\,h^2$.
Angle iron; equal flanges, of width b	$\frac{1}{24}\,b^2$.
Angle iron; unequal flanges, of widths b and h.	$\frac{b^2h^2}{12\,(b^2 + h^2)}$.
Cross of equal arms	$\frac{1}{24}\,h^2$.
H-iron; breadth of flanges, b; area, A; area of *web*, B	$\frac{b^2}{12} \cdot \frac{A}{A + B}$.
Channel iron; depth flange + $\frac{1}{2}$ thickness of *web* $= h$; area *web* $= B$; area flanges $= A$	$h^2\left(\frac{A}{12\,(A + B)} + \frac{AB}{4\,(A + B)^2}\right)$

The value of C is 36,000; $a = \frac{1}{36000}$ for wrought iron: $C = 80{,}000$; $a = \frac{1}{6400}$ for cast iron; h = least dimension.

For octagonal and other sections approaching either of the above figures, the nearest regular figures may be takan.

Columns should always yield by alteration of form, and not by local injury.

The investigations of Hodgkinson, which form the basis of the engineer's work in this direction, indicated that, in practice, the strength of *long* columns with fixed ends is three times as great as those with joints or rounded ends; that the column or strut having one fixed and one rounded or loose end, is intermediate, the three cases having the relation 1, 2, 3. When having flat ends, they yield at three points—in the middle and near each end—when rounded or loose, in the middle only. The increase of the diameter at the middle gives greater strength to solid pillars, but has little effect on hollow columns; the gain, in the first case, is 10 or 12 per cent. The load carried on columns of similar form varies as the cross section.

Cast-iron Columns are used in many structures, and, if sound and of good material, are reliable. They are economical in cost of manufacture and of fitting, and are more durable when exposed to the weather than are columns of wrought iron. They are less safe where exposed to shock, and are, for that reason, seldom used in bridges or in structures liable to injury by that cause. Cast-iron pillars are more liable to defects of form of structure and of material than those of wrought iron; they are also more subject to injury by shock; they should always be designed with a higher factor of safety than wrought-iron pillars. The engineer has less confidence in cast iron, also, because of the difficulty of testing and of inspecting it satisfactorily. Cast-iron columns should not be given a thickness less than about $0.004l$, nor in any case less than $\frac{5}{8}$ inch (1.6 centimetres). Some engineers make this limit $0.1d$. Slight inequalities of thickness do not usually impair their strength.

The flanges of columns should be turned and fitted to the base, which should itself be smoothly faced to receive the column. Where the ends can be spread to form capital and base, the structure is greatly stiffened.

For short pillars of large diameter, cast iron is stronger than wrought.

A moderately hard, strong, close-grained iron is best for columns, as well as for beams or other structures in which stiffness is essential.

Sections Other than Rectangular are most common in iron and steel beams and girders. For the general case we have, as can be shown, for moderate deflections:

$$M = \frac{RI}{y_1}$$

where M is the moment of resistance to bending offered by the beam; I is the Geometrical Moment of Inertia of the strained section, and y_1 is the distance of the neutral axis of the beam from the adjacent surface, when either tension or compression acts alone to produce M. When the neutral axis is at the middle of the section, and the resistances are equal above and below, the *total* moment of resistance becomes,

$$M = 4\ R\frac{I}{d}$$

d being the depth of the strained section.

Prof. C. A. Smith gives a simple, handy rule for the moment of resistance of sections of "tee" and "angle" irons exposed to flexure, thus:*

One-fourth the product of breadth, depth, and thickness of flange, in inches, is the moment of resistance in foot-tons; *i.e.*,

$$\frac{bdt}{4} = M \text{ nearly.}$$

In metric measures, the divisor becomes 200 to give the moment in metre-tonnes.

The quantity thus obtained being taken as the working load, the maximum stress is about 10,000 pounds per square inch (703 kilogrammes per square centimetre).

The values of R given in the tables are not exact for

* *Railroad Gazette*, Nov. 13, 1875.

beams and girders of other than rectangular section, or for cases in which the neutral axis shifts its position under the load. If the value of R is taken as equal to the smaller of the two values T and C, any error will be on the safe side; or the factor of safety may be somewhat increased to allow for an overestimate.

The forms of section adopted will be seen in Article 270, on the working formulas for beams. It is evident that, in general, extending the extreme portions of the section where stresses become greatest, and restricting the intermediate part, or the "web," to the size needed to hold the other portions in proper relative positions, will produce forms of beam of greater strength, with a given weight of material, than can be obtained in the cases of rectangular, circular, or other simple forms of section.

Where the metal has equal strength to resist tension and compression, it is further evident that the top and bottom "flanges" should be of equal size; this constitutes the Tredgold "I-beam" usually made in wrought iron. When the metal is stronger in compression than in tension, as is the case with cast iron, the extended side should be enlarged; this was done by James Watt when making his "⊥-beam," and by Fairbairn and Hodgkinson, who first made the "I-beam," in which the compressed flange has an area less than that under tension in the same proportion that the resistance to compression exceeds the resistance to tension. For ordinary cast iron these areas are as six to one.

In many cases the form of section is determined by convenience in making or in building up. Beams and columns are often constructed of L, or "angle" iron, with plate iron, or with ⊔, or "channel" iron, built up in various ways to form I-beams, ⌶-beams, or various sections approaching hexagonal or circular.

For all such cases the moment of inertia can be determined and inserted in the general formulas.

The transverse strength of "round iron" and steel of circular section may be taken as six-tenths the strength of bars of square section circumscribing the circle.

According to Grashof a circular plate will bear a pressure if bolted along the edge,

$$p = \frac{3}{2}\,\frac{Tt^2}{r^2}$$

when T is the tenacity, t the thickness, and r the radius, similar units being used throughout.

Shearing is produced by sets of opposed forces acting in the same or parallel planes, as where a punch is used or where metal is "sheared."

The shearing resistance of iron is usually taken as equal to its resistance to tension, and varies with form and dimensions from 45,000 to 60,000 pounds per square inch (3,164 to 4,218 kilogrammes per square centimetre). The shearing resistance of steel varies from that of good wrought iron to double that value or more, according to its composition. Steel is usually, however, less capable of resisting "unfair" strains than is iron, and a good value of this form of resistance may be taken as

$$\left.\begin{aligned} S &= 60{,}000 + 40{,}000\,C \\ S_m &= 4{,}218 + 2{,}812\,C \end{aligned}\right\}$$

where C is the percentage of carbon.

The shearing strength of cast iron varies irregularly from 15,000 to 40,000 pounds per square inch (1,055 to 2,812 kilogrammes per square centimetre) of sheared section, and is most safely taken at the lower figure. Its value is usually not far from that of the tensile resistance to which it may be taken as equal. The resistance of boiler plates to punching, of riveted wrought iron-work and of iron bridge pins to shearing has been found variable with ordinary materials between the limits, usually, of 50,000 and 55,000 pounds per square inch (3,515 to 3,866 kilogrammes), and may be taken in estimates and specifications at the lower amount. A very extensive set of experiments upon the strength of bolts and nuts, conducted by the Author, gave figures lower than the above by 20 per cent. or more.

In consequence of the liability, which is always to be apprehended, that the shearing will not take place in such a manner as to permit the piece sheared to offer its maximum resistance, it is usual to assume a loss of from one-fourth to one-fifth, and to take $S = \frac{4}{5}T$, or $S = \frac{3}{4}T$. Taking the latter proportion, the ordinary working value of S becomes, for iron 40,000 to 45,000 pounds, and

$$\left.\begin{aligned} S' &= 48{,}000 + 32{,}000\,C \\ S'_m &= 3{,}374 + 2{,}250\,C \end{aligned}\right\}$$

for steel, which value may be used in all ordinary constructions built of known grades of good metal. For other cases not settled by experiment, the engineer assumes the maximum shearing resistance as nearly equal to the tenacity of the metal.

Coupling bolts, in shaft couplings, are exposed to this action. They may be proportioned either by making this stress, as above, a safe minimum, or by direct calculation from the size of shaft, as is done by Rankine, who makes their diameter,

$$d = \sqrt{\frac{d'^3}{3nr}}$$

in which d is the diameter of the bolt, d' that of the shaft, n the number of bolts, and r the radius of the circle passing through their centres.

Riveted work is subject to injury by the tearing out of the rivets through the sheet, when the shearing resistance of the latter is too low, by pulling off the heads when the stress is in line with the axis of the rivet, and by the shearing of the rivet when of too small area of section. The joint has maximum value when no more likely to yield in one of these ways than in another. *Loosely* fitted rivets and pins have from $\frac{1}{2}$ to $\frac{1}{3}$ the shearing resistance of tightly fitted rivets; which latter have practically the full strength due the section sheared. The diameter of the rivet should be about twice

the thickness of the plate, but the size is often determined by practical considerations. A common range of sizes is the following, although no fixed rule is settled upon:

SIZE OF RIVETS.

Thickness of plate, inches		$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
" " "	centimetres	0.48	0.64	0.80	0.96	1.12	1.27	1.60	1.92
Diameter of rivet, inches		$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$
" " "	centimetres	1.27	1.60	1.92	2.08	2.08	2.54	3.17	3.81

The distance between centres, the *pitch* of the rivets, should be, in iron,

$$p = 0.7854\frac{d^2}{t} + d$$

where d is the diameter of the rivet, t the thickness of the sheet.

In steel, the same rule applies when riveted with rivets of the same quality with the sheet; otherwise, we must have, when S is the shearing resistance per unit of area of the rivet-section, and S' that of the sheet,

$$S\frac{\pi d^2}{4} = S'(p - d)t,$$

and

$$p = \frac{S}{S'}\frac{\pi d^2}{4t} + d$$

$$= 0.7854\frac{Sd^2}{S't} + d$$

When the sheet is of rather hard steel and the rivet of iron, the sheet is liable to cut the rivet, and the value of S should therefore be taken low.

The length of the rivet is usually about

$$l = 2t + 2\tfrac{1}{4}d$$

exceeding the length of the rivet hole by $2\frac{1}{4}$ times its diameter.

For double riveting and joints held by several rows, n, of rivets,

$$p = 0.7854\frac{Snd^2}{S't} + d.$$

The lap of the joint should be sufficient to allow ample margin for chipping or planing and caulking, as well as safe against the tearing out of the rivet.

Fairbairn gives the following table as exhibiting the proportions by him determined experimentally:

PROPORTION OF RIVETS.

THICKNESS OF PLATE.		DIAMETER OF RIVETS.		LENGTH OF RIVETS.		LAP OF SINGLE RIVETING.		PITCH OF RIVETS.	
In.	Cm.	In.	Cm.	In.	Cm.	In.	Cm.	In.	Cm.
$\frac{3}{16}$	0.48	$\frac{3}{8}$	0.95	$\frac{7}{8}$	2.22	$1\frac{1}{4}$	3.18	$1\frac{1}{4}$	3.18
$\frac{1}{4}$	0.64	$\frac{1}{2}$	1.27	$1\frac{1}{8}$	2.86	$1\frac{1}{2}$	3.81	$1\frac{1}{2}$	3.81
$\frac{5}{16}$	0.79	$\frac{5}{8}$	1.59	$1\frac{3}{8}$	3.49	$1\frac{7}{8}$	4.76	$1\frac{5}{8}$	4.13
$\frac{3}{8}$	0.95	$\frac{3}{4}$	1.91	$1\frac{5}{8}$	4.13	2	5.08	$1\frac{3}{4}$	4 45
$\frac{1}{2}$	1.27	1	2.54	$2\frac{1}{4}$	5.72	$2\frac{1}{4}$	5.72	2	5.08
$\frac{5}{8}$	1.59	$1\frac{1}{4}$	3.17	$2\frac{3}{4}$	6.99	$2\frac{3}{4}$	6.99	$2\frac{1}{2}$	6.35
$\frac{3}{4}$	1.91	$1\frac{1}{2}$	3.81	$3\frac{1}{4}$	8.26	$3\frac{1}{4}$	8.26	3	7.62

Engineer-in-Chief W. H. Shock, U. S. N.,* finds bolts or rivets in double shear to exceed in resistance those in single shear by the following amount:

$\frac{1}{8}$ inch (1.27 cm.) diameter..... 86.2 per cent.
$\frac{5}{8}$ inch (1.59 cm.) diameter..... 97.0 per cent.
$\frac{3}{4}$ inch (1.9 cm.) diameter.....101.1 per cent.
$\frac{7}{8}$ inch (2.22 cm.) diameter..... 82.6 per cent.
1 inch (2.54 cm.) diameter..... 85.0 per cent.

The Torsion of Shafts may be reckoned as a case of shearing. The following are safe formulas:

* Treatise on Steam Boilers, W. H. Shock. N. Y.: D. Van Nostrand, 1881.

For head shafts well supported against springing:

$$P=\frac{d^3R}{125}=\frac{d_m{}^3R}{2000};\ d=\sqrt[3]{\frac{125HP}{R}};\ d_m=\sqrt[3]{\frac{2000HP}{R}}.$$

For line shafting; hangers 8 *feet* ($2\frac{1}{2}$ *metres*) *apart:*

$$P=\frac{d^3R}{90}=\frac{d_m{}^3R}{1450};\ d=\sqrt[3]{\frac{90HP}{R}};\ d_m=\sqrt[3]{\frac{1450HP}{R}}.$$

For transmission simply; no pulleys:

$$P=\frac{d^3R}{62.5}=\frac{d_m{}^3R}{1000};\ d=\sqrt[3]{\frac{62.5HP}{R}};\ d_m=\sqrt[3]{\frac{1000HP}{R}}.$$

For cold-rolled iron, these formulas become:

$$HP=\frac{d^3R}{75}=\frac{d_m{}^3R}{1200};\ d=\sqrt[3]{\frac{75HP}{R}};\ d_m=\sqrt[3]{\frac{1200HP}{R}}.$$

$$HP=\frac{d^3R}{55}=\frac{d_m{}^3R}{880};\ d=\sqrt[3]{\frac{55HP}{R}};\ d_m=\sqrt[3]{\frac{880HP}{R}}.$$

$$HP=\frac{d^3R}{35}=\frac{d_m{}^3R}{550};\ d=\sqrt[3]{\frac{35HP}{R}};\ d_m=\sqrt[3]{\frac{550HP}{R}}.$$

Here HP = horse-power transmitted; d = diameter of shaft in inches; d_m in centimetres; R = revolutions per minute.

Francis gives the following as permissible distances between bearings for shaftings carrying no side strain:

SPANS FOR SHAFTING.

DIAMETER OF SHAFT.		DISTANCE BETWEEN BEARINGS.			
		Wrought Iron.		Steel.	
Inches.	Centimetres.	Feet.	Metres.	Feet.	Metres.
2	5.08	15.5	4.7	15.9	4.8
3	7.62	17.7	5.4	18.2	5.5
4	10.16	19.5	6.0	20.0	6.1
5	12.70	20.9	6 4	21.6	6.5
6	15.24	22.3	6.8	22.9	6.9
7	17.78	23.5	7.1	24.1	7.3
8	20.32	24.6	7.5	25.2	7.7
9	22.86	25.5	7.8	26.2	8.0

These distances may usually be safely obtained from the formulas:

$$D = 12\sqrt[3]{d};\ D_m = 3\sqrt[3]{d_m}$$

where D, D_m are distances in British and metric measures, between bearings, d, d_m are the diameters of the shafts.

In designing steam-engine shafts and other similar pieces the diameter is sometimes expressed in other terms. Thus the Author has used, in designing, the formula, for a single shaft, for long-stroked engines,

$$d = \sqrt[3]{\frac{d'^2 pL}{250}}$$

in which d is the minimum diameter of the shaft in inches, d' that of the steam cylinder in inches, and L the stroke of piston in feet, and p the steam pressure in pounds per square inch. In metric measures, kilogrammes, and centimetres,

$$d_m = 11\sqrt[3]{d^2 pl},\ \text{nearly}$$

For screw engines the diameter is usually from one-eighth to one-sixth greater.

Shafts are generally made of wrought iron; cold-rolled shafting is common; steel shafts and shafting are coming into use, both of common and Whitworth steel.

Cast iron is rarely used to resist this kind of stress.

The Metals, and their Strain Diagrams.*—Fig. 64 exhibits a series of curves which illustrate well the general characteristics and the peculiarities of representative specimens of the principal varieties of useful metals. In some cases two specimens have been chosen for illustration, of which one presents the average quality, while the other is the best and most characteristic of its class.

Wrought iron, as usually made, has a somewhat fibrous structure, which is produced by particles of cinder, originally left in the mass by the imperfect work of the puddler while forming the ball of sponge in his furnace, and which, not having been removed by the squeezers or by hammering the puddle ball, are, by the subsequent process of rolling, drawn out into long lines of non-cohering matter, and produce an effect upon the mass of metal which makes its behavior under stress somewhat similar to that of the stronger and more thready kinds of wood. In the low steels, also, in which, in consequence of the deficiency of manganese accompanying, almost of necessity, their low proportion of carbon, this fibrous structure is produced by cells and "bubble holes" in the ingot refusing to weld up in working, and drawing out into long microscopic, or less than microscopic, capillary openings.

In consequence of this structure we find a depression interrupting the regularity of their curves, immediately after passing the limit of elasticity, precisely as the same indication of the lack of homogeneousness of structure was seen in the diagrams produced by locust and hickory.†

The presence of internal strain constitutes an essential peculiarity of the metals which distinguishes them from or-

* From a paper by the Author; *Trans. Am. Soc. C. E.*, 1874. † M. of E.

ganic materials. The latter are built up by the action of molecular forces, and their particles assume naturally, and probably invariably, positions of equilibrium as to strain. The same is true of naturally formed inorganic substances. The metals, however, are given form by external and artificially produced forces. Their molecules are compelled to assume certain relative positions, and those positions may be those of equilibrium, or they may be such as to strain the cohesive forces to the very limit of their reach. It even frequently happens, in large masses, that these internal strains actually result in rupture of portions of the material at various points, while in other places the particles are either strongly compressed, or are on the verge of complete separation by tension. This peculiar condition must evidently be of serious importance where the metal is brittle, as is illustrated by the behavior of cast iron, and particularly in ordnance. Even in ductile metals it must evidently produce a reduction in the power of the material to resist external forces.

Since straining the piece to the limit of elasticity brings all particles subject to this internal strain into a similar condition, as to strain, with adjacent particles, it is evident that indications of the existence of internal strain, and, through such indications, a knowledge of the value of the specimen, as affected by this condition, must be sought in the diagram before the sharp change of direction which usually marks the position of the limit of elasticity is reached. As already seen, the initial portion of the diagram, when the material is free from internal strain, is a straight line up to the limit of elasticity. A careful observation of the tests of materials of various qualities, while under test, has shown that, as would, from considerations to be stated more fully hereafter in treating of the theory of rupture, be expected, this line, with strained materials, becomes convex toward the base line, and the form of the curve, as will be shown, is parabolic. The initial portion of the diagram, therefore, determines readily whether the material tested has been subjected to internal strain, or whether it is homogeneous as to strain.

This is exhibited by the *direction* of this part of the line as well as by its form. The existence of internal strain causes a loss of stiffness, which is shown by the deviation of this part of the line from the vertical to a degree which becomes observable by comparing its inclination with that of the line of elastic resistance obtained by relaxing the distorting force —*i.e.*, the difference in inclination of the initial line of the diagram and the lines of elastic resistance, *e*, *e*, *e*, indicates the amount of existing internal strains.

Strain Diagram of Forged Iron.—In Fig. 64 the curves numbered 6, 1, 22 and 100, are the diagrams produced by three characteristic grades of wrought iron. The first is a quality of English iron, well known in our market as a superior metal. The second is one of the finest known brands of American iron, and the third is also of American make, but it does not usually come into the market in competition with well-known irons, in consequence of the high price which is consequent upon the necessary employment of an unusual amount of labor in securing its extraordinarily high character.

No. 6 at first yields rapidly under moderate force, only about 50 foot-pounds of torsional moment being required to twist it 5°. It then rapidly becomes more rigid, as the internal strains, so plainly indicated, are lost in this change of form, and at 6° of torsion the resistance becomes 60 foot-pounds, as measured at *a*. Here the elastic limit is reached. The next 3° produce no increase of resistance. This fact shows that this iron, which was not homogeneous as to strain, was also not homogeneous in structure. We conclude that it must be badly worked and seamy, and that it may have been rolled too cold; the former is the probable reason of its lack of homogeneous structure; the latter gave it its condition of internal strain. After the first 9° of torsion, resistance steadily rises to a maximum, which is reached only when just on the point of rupture, and the piece finally commences breaking at 250°, and is entirely broken off at 285°. Its maximum elongation, whose value is proportionable to the reduction of section noted with the standard testing machines, is 0.691.

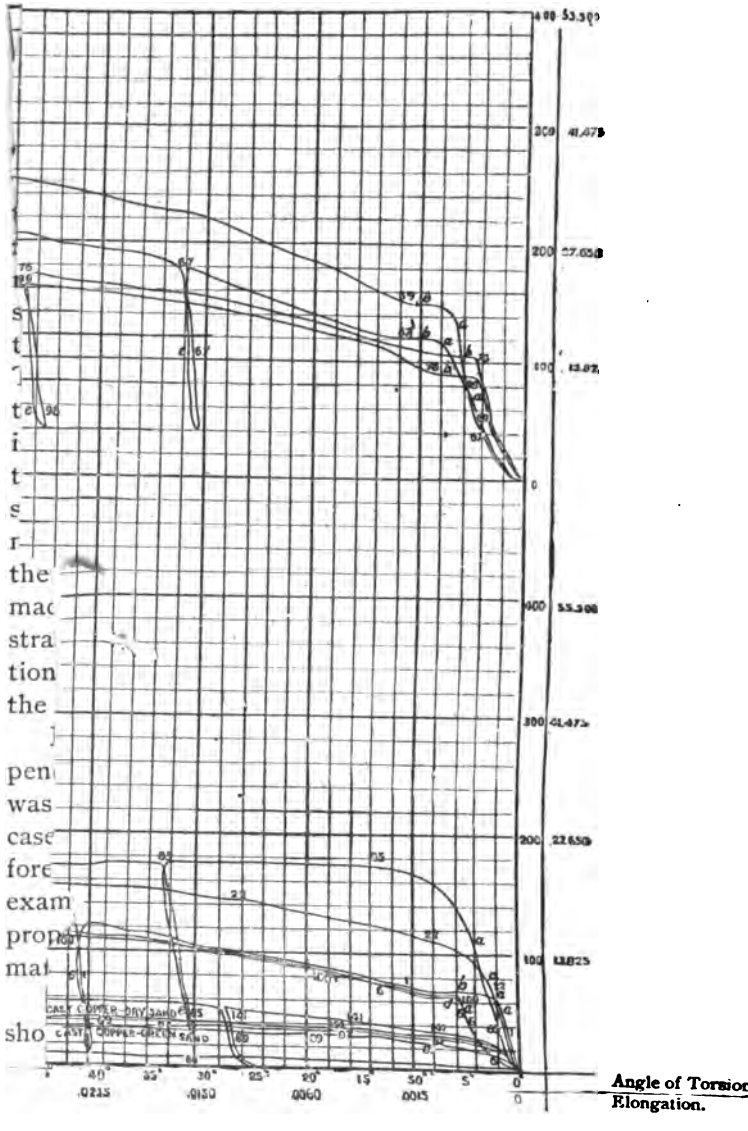
The terminal portion of the line, after rupture commences, is not usually accurate as a measure of the relation of the force to the distortion. The increase of resistance between the angle 9° and the angle of rupture is produced by the additional effort in resistance due to the "flow," or drawing out of particles, as already indicated.

Applying the scale for tension, which in the case of these curves was very exactly 24,000 pounds per square inch for each inch measured vertically on the diagram, we find that the elastic limit was passed under a stress equivalent to a tension of 19,800 pounds per square inch, and that the ultimate tenacity was 59,200 pounds per square inch. When nearly at the maximum the specimen was relieved from stress, the pencil descending to the base line, and the elasticity of the piece produced a certain amount of recoil. The angle intercepted between the foot of this nearly vertical line, *c*, and the origin at *O*, measures the *set*, which is almost entirely permanent. The distance measured from the foot of the perpendicular let fall upon the axis of abscissas, from the head of this line to the foot of the line *e*, measures the elasticity, and is inversely proportional to the modulus. A comparison of the inclination of the line made by the pencil in reascending, on the renewal of the strain with the initial line of the diagram, gives the indication of the amount of internal strain originally existing in the piece.

It will be noticed that the horizontal movement of the pencil is recommenced at *I*, under a higher resistance than was recorded before the elastic line was formed. In this case the piece had been left under strain for some time before the stress was relieved, and the peculiarity noted is an example of an increase of resistance under stress,* or more properly of the elevation of the elastic limit, of which more marked examples will be shown subsequently.

The exceptional stiffness and limited elastic range here shown, as compared with the other examples given, is prob-

* *Vide* Transactions Am. Soc. C. E., Vol. II., page 290.



Torsional Moments.
Foot-Pounds.
Kilogram-metres.
400 53.300
300 41.475
200 27.650
100 13.825
0
400 55.300
300 41.475
200 27.650
100 13.825
CAST COPPER-DRY SAND
CAST COPPER-GREEN SAND
40° 35° 30° 25° 20° 15° 10° 5° 0°
.0215 .0150 .0060 .0015 0
Angle of Torsion,
Elongation.

ably a phenomenon accompanying and due to this increase of resistance under stress.

Examining No. 1 in a similar manner, we find that it is far freer from internal strain than No. 6, its initial line being much more nearly straight and rising more rapidly. It is rather less homogeneous in structure, and is forced through an arc of 6°, after having passed its elastic limit, before it begins to offer an increasing resistance. It is evidently a better iron, but less well worked, and, as shown by the position of the elastic limit, is somewhat harder and stiffer. No. 1 retains its higher resistance quite up to the point at which No. 6 received its incidental accession of resistance by standing under strain, and the two pieces break at, practically, the same point; No. 1 having slightly the greater ductility. When the "elastic line," *e*, is formed just before fracture, it is seen that No. 1 has a greater elastic range and a lower modulus than No. 5. The elastic line formed by No. 1 at between 40° and 45° of torsion is seen to be very nearly parallel with that obtained near the terminal portion of the diagram, and illustrates the fact, here first revealed to the eye, that the elasticity of the specimen remains practically unchanged up to the point of incipient rupture; and this fact corroborates the deductions of Wertheim* and others who came to this conclusion from less satisfactory modes of research.

No. 22 illustrates the characteristics of a metal which represents one of the best qualities of wrought iron made, and with which every precaution has been taken to secure the greatest possible perfection, both in the raw material and in its manufacture. The line of this diagram, starting from *O*, rising with hardly perceptible variation from its general direction, turns, at the elastic limit, *a*, under a moment of about 80 foot-pounds, equivalent to a tension of about 24,000 pounds per square inch (1,680 kilogrammes per square cm.); and with between 2° and 3° of torsion only, and thence continues rising in a curve almost as smooth and reg-

* *Vide* Annales de Chimie et de Physique.

ular as if it had been constructed by a skilful draughtsman. Reaching a maximum of resistance to torsion of 220 foot-pounds and an equivalent tensile resistance of over 66,000 pounds per square inch (4,620 kilogrammes per square centimetre) at an angle of 345°, it retains this high resistance up to the point of rupture, some 358° from its starting point. The maximum elongation of its exterior fibres is 1.2, making them at rupture 2.2 times their original length. This would produce a probable breaking section in the common testing machine equal to 0.4545 of the original section.

From the beginning to the end this specimen exhibits its superiority, in all respects, over the less carefully made irons, Nos. 1 and 6, which are themselves good brands. The homogeneousness of No. 22 is almost perfect, both in regard to strain and to structure, the former being indicated by the straightness of the first part of the diagram and its parallelism with the "elastic line," *e*, produced at 217°, and the latter being proven by the accuracy with which the curve follows the parabolic path indicated by theory as that which should be produced by a ductile homogeneous material. At similar angles of torsion, No. 22 offers invariably much higher resistance than either Nos. 1 or 6, and this superiority, uniting with its much greater ductility, indicates an immensely greater resilience. It is evident that for many cases, where lightness combined with capacity to carry live loads and to resist heavy shocks are the essential requisites, this iron would be by far preferable, notwithstanding the cost of its manufacture, to any of the cheaper grades. Comparing their elasticities, as shown at 210°, 215°, it is seen that No. 22 is about equally stiff and elastic with No. 1, while both have a wider elastic range and are less rigid, and hence are softer, than No. 6, whose elastic line is seen at 221°. All of the characteristics here noted can be accurately gauged by measuring the diagrams.

No. 100 is the curve obtained from a piece of Swedish iron. Its characteristics are so well marked that one familiar with the metal would hardly fail to select this curve from among those of other irons. It softness and its homogeneous

structure are its peculiarities. Its curve, at first, coincides perfectly with that of No. 6. It has, however, slightly less of the condition of internal strain, and a somewhat higher limit of elasticity. The elastic limit is found at 5½° of torsion, and at a stress of 65 foot-pounds (9.1 kilogrammetres) of moment, equivalent to 19,500 pounds on the square inch (1,365 kilogrammes per square centimetre), in tension. Its increase of resistance, as successive layers are brought to their maximum and begin to flow, is very nearly the same as that of the specimens Nos. 1 and 6, and the line lies between the diagrams given by these irons up to 30°, and then falls slightly below the latter. At 220° it attains a maximum resisting power, and here the outer surface begins to rupture, after an ultimate stretch of lines formerly parallel to the axis amounting to 0.564. Had this elongation taken place in the direction of strain, as in the usual form of testing machine, it would have produced a reduction of section to 0.64 the original area.* At this point the stress in tension equivalent to the 176 foot-pounds (24.64 kilogram metres) of torsional stress, is 52,800 pounds per square inch (3,696 kilogrammes per square centimetre). From 250° the loss of resistance takes place rapidly, but the actual breaking off of the specimen did not occur until it had been given a complete revolution. This part of the diagram distinguishes the metal from all others, and shows distinctly the exceptionally tough, ductile and homogeneous character which gives the Swedish irons their superiority in steel making. No. 22, even, although much more extensible, is harder than No. 100, and yields more suddenly when it finally gives way.

Inspection of Fractured Test Pieces.—An examination of the broken test piece gives evidence confirmatory of the record. Thus, examining the broken test pieces from the autographic machine, as shown below, and comparing them, it will be found that the specimens themselves furnish almost as valuable information, after test, as the diagrams give, and they should always be carefully inspected with a

* Compare Styffe, Strength of Iron and Steel, p. 133, Nos. 26-30.

view to securing additional or corroborative information. Fig. 65 is a sketch of specimen No. 1, and shows its somewhat

FIG. 65.

FIG. 66.

granular fracture, and the seamy structure produced by a defective method of working. Fig. 66, from specimen No. 16, more nearly resembles that which gave the diagram marked 6, Fig. 64. The metal is seen to be good, tough, and better in quality than No. 1, but it is even more seamy, and even less thoroughly worked, as is evidenced by the cracks extending around the neck, and by the irregularly distributed flaws seen on its end.

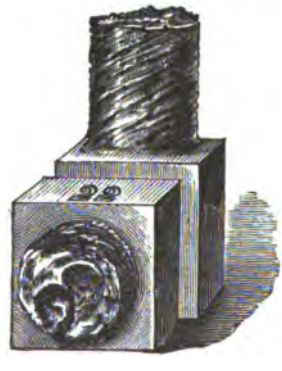


FIG. 67.

Fig. 67 exhibits the appearance of No. 22 after fracture, and shows, even more perfectly than the pencilled record, the excellent character of the material. The surface of the neck was originally smoothly turned and polished, and carefully fitted to gauge. Under test it has become curiously altered, and has assumed a rough, striated appearance, while the helical markings extend completely around it. The end has the peculiar appearance which will be seen to be characteristic of tough and ductile

metals, and the uniformly bright appearance of every particle in the fractured section shows how all held together up to the instant of rupture, and that fracture finally took place by true shearing. Rupture by torsion thus brings to light every defect and reveals every excellence in the specimen. Rupture by tension rarely reveals more than the mere strength of the material.

Strain-Diagrams of Low Steels.—In Fig. 64, and above the curves just described, are a set obtained during experiments on "low steels," produced by the Bessemer and Siemens-Martin processes. In general character the curves are seen to resemble those of the standard irons, as illustrated by Nos. 1 and 6. The irons contain usually barely a trace of carbon. These steels contain from one-third to five-eighths of one per cent. The irons are made by a process which leaves them more or less injured by the presence of impurities, from which the utmost care can never free them. The steels are made from metal which has been molten and cast, a process which allows a far more complete separation of slag and oxides. The low steels, however, are liable to an objectionable amount of porosity, due to the liberation of gas while the molten mass is solidifying, whenever the spiegeleisen, employed as a conveyer of carbon, carries little manganese. The results of these differences in constitution and treatment are readily seen by inspecting the curves. They show a stiffness equal to No. 6, and about the same degree of internal strain. They contain a sufficient number of the capillary channels produced by drawing down the pores while working the ingot into bar, to cause a lack of homogeneousness in structure very similar to that produced in iron by cinder. They have a much higher elastic limit and greater strength, and the softer grades have great ductility. In resilience, these softest steels excel all other metals, except the unusual example No. 22, and are evidently the best materials that are now obtainable for all uses where a tough, strong, ductile metal is needed to sustain safely heavy shocks. A comparison of the diagrams of two competing metals may thus be made to indicate how far a difference in

price should act as a bar to the use of the costlier one. For general purposes, a comparison of the resilience of the metals within the elastic limit is of supreme importance. No. 6 is seen to have more resilience within this limit than No. 1, and the steels far more than either; but No. 1 would take a set of considerable amount far within the true elastic limit, as indicated at *a*. The most valuable measure is obtained by determining the area intercepted between the "elastic line" and the perpendicular let fall from its upper end; this measures the resilience of elastic resistance, which is the really important quality.

No. 98 was cut from the head of an English Bessemer rail made from unmixed Cumberland ores. It contains nearly 0.4 per cent. carbon. It is quite homogeneous, has a limit of elasticity at 88 foot-pounds of torsional, or 26,400 pounds per square inch tensile stress, approaches its maximum of resistance rapidly, and at 210° the torsional moment becomes 225 foot-pounds, equivalent to 67,500 pounds per square inch tensile stress. It only breaks after a torsion of 283°, and with an ultimate elongation of 80 per cent., equivalent to a reduction of cross section to 0.556.

No. 76 is a Siemens-Martin steel made from mixed Lake Superior and Iron Mountain ores, and contained about the same amount of carbon as the preceding. It contains rather more phosphorus, which probably gives it its somewhat greater hardness, its higher limit of elasticity, and its somewhat reduced ductility. Its elastic limit is found at 104 foot-pounds of torsion, or 31,200 pounds tensile resistance, and its ultimate strength is almost precisely that of the preceding specimen. Its elongation is 0.66 maximum. Unless more seriously affected by extreme cold than No. 98, it would be preferred for rails, and, perhaps, for most purposes.

No. 67 is a somewhat "higher" steel, made by the same process. It is less homogeneous than the two just examined, has greater strength and a higher elastic limit, but less ductility. Its resilience is very nearly the same as that of Nos. 98 and 76. The elasticity of all these steels seems very exactly the same. The ductility of No. 67 is measured by

0.40 elongation. At *d*, is seen another illustration of elevation of the elastic limit. The piece was left twenty-four hours under maximum stress. The torsional force was then removed entirely. On renewing it, as is seen, the resistance of the specimen was found increased in a marked degree.

No. 69 is an American Bessemer steel, containing not far from 0.5 per cent. carbon. The same effect is seen here that was before noted, an increase of hardness, a higher elastic limit, and greater strength, obtained, however, by some sacrifice of both ductility and resilience. The elastic limit is approached at 130 foot-pounds of torsional moment, or 39,000 pounds tensile, and the maximum is 280 foot-pounds of moment and 84,000 pounds tensile resistance at 133°. Its maximum angle of torsion is 150°, its elongation 0.24.

No. 85 is a singular illustration of the effects of what is probably a peculiar modification of internal strain. It seems to have no characteristics in common with any other metal examined. Its diagram would seem to show a perfect homogeneousness as to strain, and a remarkable deficiency of homogeneity in structure. It begins to exhibit the indications of an elastic limit at *a*, under a torsional moment of 110 foot-pounds, or an apparent tensile stress of 33,000 pounds per square inch, and then rises at once, by a beautifully regular curve, to very nearly its maximum at 16°, and 176 foot-pounds. The maximum is finally reached at 130°, and thence the line slowly falls until fracture takes place at 195°. The maximum resistance seems* to be very exactly 60,000 pounds to the square inch. Its maximum elongation for exterior fibres is about 0.23. The resilience, taken at the elastic limit, is far higher than with common iron, and it is seen that this metal, in many respects, may compete with steel. Its elasticity was seen to remain constant wherever taken. This specimen was a piece of "cold-rolled" iron. It is probably really far from homogeneous as to strain, but its artificially pro-

* In exceptional cases, of which this is an example, this scale for tension gives too high values. The tensile strength is usually rather less than above given.

duced strains are symmetrically distributed about its axis, and being rendered perfectly uniform throughout each of the concentric cylinders into which it may be conceived to be divided, the effect, so far as this test, or so far as its application as shafting, for example, is concerned, is that of perfect homogeneousness. The homogeneousness in structure is readily explained by an examination of the pieces after fracture; they are fibrous, and have a grain as thread-like as oak; their condition is precisely what is shown by the diagram, and the metal itself is as anomalous as its curve.

Strain Diagrams of Tool Steels.—The "tool steels" differ chemically from the "low steels" in containing a higher percentage of carbon, and usually in being very nearly, though not absolutely, free from all injurious elements. Containing a higher proportion of carbon than the preceding class of metals, it is comparatively easy to secure homogeneousness by the introduction of manganese, and, by the same means, to eliminate very perfectly the evil effects of any small proportion of sulphur that may be present. Their comparatively large admixture of carbon makes them harder and reduces their ductility, and since the reduction of ductility occurs to a greater degree than the increase of strength, the effect is also to reduce their resilience. The working of these metals is more thorough than is that of the less valuable steels or of iron. They are cast in comparatively small ingots, and are frequently drawn down under the hammer, instead of in the rolls, and are thus more completely freed from that form of irregularity in structure noticed so invariably in steels otherwise treated. The effect of increasing the proportion of carbon is to confer upon iron the property of hardening when heated to a high temperature and suddenly cool, and the invaluable property of "taking a temper." The hardened steels are, however, comparatively brittle, the hardening being secured at the expense of ductility.

Referring to the figure, a set of diagrams will be found, having their origin at 180°, which are *fac-similes* of those automatically produced during experiments upon various kinds of tool steels.

No. 58 is an English metal, known in the market as "German crucible steel." It is remarkable as having a condition of internal strain which has distorted its diagram to such an extent as to completely hide the usual indication of the elastic limit. A careful inspection shows what may be taken for this point at about 14½° of torsion, when the twisting moment was about 120 foot-pounds, and the tensile resistance 36,000 pounds per square inch (2,531 kilogrammes per square millimetre). The metal is homogeneous in structure, has an ultimate resistance of 302 foot-pounds of moment, or 90,600 pounds per square inch tensile resistance (6,369 kilogrammes per square millimetre). Its resilience is evidently inferior to that of the softer metals, and also less than the next higher and better grades. This metal contains about 0.60 to 0.65 per cent. carbon. Its elongation amounts to 0.045.

No. 53 is an English "double shear steel," of evidently very excellent structure, but less strong and less resilient than the preceding. Its exterior fibres are drawn out three per cent.

Nos. 41 and 61 are two specimens of one of the best English tool steels in our market. The first was tested as cut from the bar, but the second was carefully annealed before the experiment. In this instance annealing has caused a slight loss of resilience as well as a decided loss of strength. In No. 41 the limit of elasticity can hardly be detected, but seems to be at about the same point as in No. 61, at near 130 foot-pounds moment, and 39,000 pounds tension. The ultimate strength is nearly 119,000 pounds per square inch. The proportion of carbon is very closely 1 per cent. Its section would reduce by tension 0.05.

No. 70 is an American "spring steel," rather hard, but, as shown by its considerable resilience, of excellent quality, resembling remarkably the tool steel No. 41. It differs from the latter apparently by its much higher elastic limit. It is possible that this may have been caused by more rapidly cooling after leaving the rolls in which it was last worked. It is evident that, for exact comparison, all specimens should be

either equally well annealed, or should be tempered in a precisely similar manner and to the same degree.

Nos. 71 and 82 are American tool steels containing about 1.15 per cent. of carbon. The former is notable as having an elastic limit at 69,000 pounds and a probable deficiency of manganese, producing the usual indication of heterogeneous structure. Both of these steels lack resilience, and are less well adapted for tools like cold chisels, rock drills, and others which are subjected to blows, than for machine tools. They have a maximum elongation, respectively, of but 0.013 and 0.03.

Inspection of Steel Test Pieces.—Interesting and instructive as the study of these curves may be made, the information obtained from them is supplemented, in a most valuable manner, by that obtained by the inspection of the fractured specimens, upon which the peculiar action of a torsional strain has produced an effect in revealing the structure and quality of the metal that could be obtained in no other way.

Fig. 68 represents the appearance of No. 68, and Fig. 69 that of No. 58, while the peculiarities of the finest tool steels

FIG. 68.

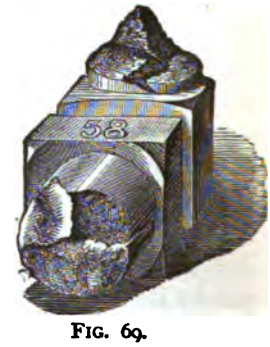


FIG. 69.

are seen in No. 71 as shown in Fig. 70. The smooth exterior of No. 68, which is a companion specimen to that giving diagram No. 69, and its bright and characteristic fracture,

resembling that of No. 22 somewhat, together indicate its nature perfectly, the first feature proving its strength and uniformity of structure, and the second showing, even to the inexperienced eye, its toughness. This is a representative specimen of low steels. No. 58 is seen to have retained, even more than No. 68, its original smoothly polished surface. Its fracture is less waxy, and much more irregular and sharply angular. The crack running down the side of the neck shows its relationship to the shear steels, which much oftener exhibit this effect of strain, in consequence of their lamellar character. No. 58 is evidently intermediate in its character between the soft steels, like No. 68, and the tool steels which are represented by No. 71, Fig. 70. In this test-piece the fracture is ragged and splintery, and the separated surfaces have a beautifully fine, even grain, which proves the excellence of the material. The surface, which was turned and polished in bringing the metal to size, remains as perfect as before the specimen was broken. By an inspection of the broken test pieces in this manner, the grade of the steel, and

FIG. 70.

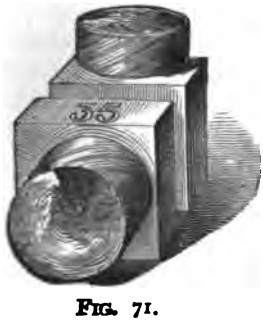


FIG. 71.

FIG. 72.

such properties also as are not revealed by an examination

of the diagram of strain, are very exactly ascertained by a novice, and, to the practiced eye, the slightest possible variations are readily distinguishable.

Fig. 71 shows the appearance of fracture of malleableized cast iron. Its semblance to wrought iron is very noticeable.

FIG. 73.

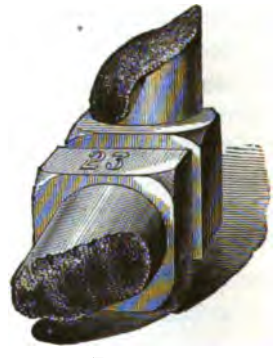


FIG. 74.

The lines running like the thread of a screw around the exterior of the neck, and the smooth, even fracture in a plane precisely perpendicular to the axis, are the instructive features. Fig. 72, representing No. 33, is a specimen similar in character to No. 37. The comparative lack of ductility, its less regular structure, and its less perfect transformation, are perfectly exhibited. Fig. 73 is an excellent cut of the white iron as cast and without malleableizing. Its surface, where fractured, has the general appearance of broken tool steel. The color and texture of the metal are distinctive, however. It has none of the "steely grain." Fig. 74 represents dark-gray cast iron. Its color, its granular structure and coarse grain, are markedly characteristic, and no one can fail to observe in the specimen the general character which is exactly given by the autographic diagrams of the testing machine.

Fractured Surfaces of Tension Test pieces.—The appearance of the fracture of good iron broken by tension

varies greatly with the rate of fracture. When broken slowly it should resemble that shown in Fig. 86 following; fractured rapidly it may become like that seen in Fig. 87 of the same article. Fig. 75 represents the appearance of a surface of slightly cold-short, but otherwise excellent iron, forged in a large mass and broken suddenly.

FIG. 75.—FRACTURE OF MASSIVE IRON.

The following is the record, and illustrates well the loss of tenacity due to forging in large sizes:

TESTS MADE AT WATERTOWN ARSENAL, MASS., OF PIECES OF BEAM STRAP.

NUMBER.	LENGTH. INCHES.	GAUGED LENGTH. INCHES.	WIDTH.	THICKNESS.	SECT'AL AREA.	PERCENTAGE OF ELONGATION.	CON. OF AREA PER CENT.	LOAD APPLIED.	LBS. PER SQ. INCH.	ELASTIC LIMIT.	CLASSIFICATION OF FRACTURE.
1	Abt. 52	20	4.80	1.88	9.02	4.3	...	370,200	41,042	31,170	Granular.
2	" 52	20	4.80	1.74	8.35	4.	3.1	325,500	38,980	25,750	Granular from fine to coarse.
3	" 52	20	4.82	1.97	9.5	3.7	16.6	383,000	40,320	26,320	Fibrous.
4	" 52	20	4.75	2.07	9.83	8.	7.	371,500	37,790	28,990	Granulur, 90 %. Fibrous, 10 %.
5	" 52	20	4.75	1.67	7.93	8.2	16.8	338,000	42,620	26,480	Fibrous.
6	" 52	20	4.75	1.74	8.26	2.2	11.1	281,000	34,020	28,450	Fibrous, 80 %. Granular, 10 %.

Nos. 1, 2, 3 were part of top of beam. Area, 5⅝ × 6¼ Average strength per square inch = 40,114 lbs. (2,820 kilogrammes per square centimetre). Average elastic limit per square inch = 27,747 lbs. (1,951 kilogrammes per square centimetre).

Nos. 4, 5, 6 were part of bottom member of strap. Average strength per square inch, 38,143 lbs. (2,681 kilogrammes per square centimetre). Average elastic limit per square inch, 27,973 lbs. (1,967 kilogrammes per square centimetre). Average strength per square inch of 1, 2, 3, 4, 5, and 6 = 39,129 lbs. (2,751 kilogrammes per square centimetre). Average elastic limit per square inch of 1, 2, 3, 4, 5, and 6 = 27,860 lbs. (1,959 kilogrammes per square centimetre).

This iron contained about 0.25 per cent. phosphorus and less than 0.1 per cent. carbon, and represents what would be considered an excellent sample of "phosphorus-iron."

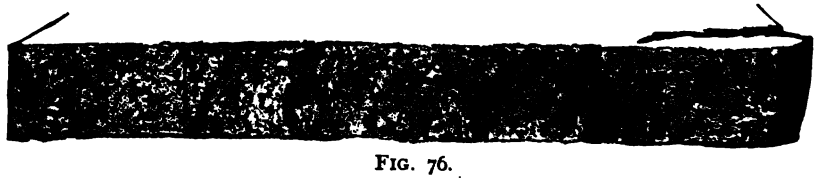


FIG. 76.

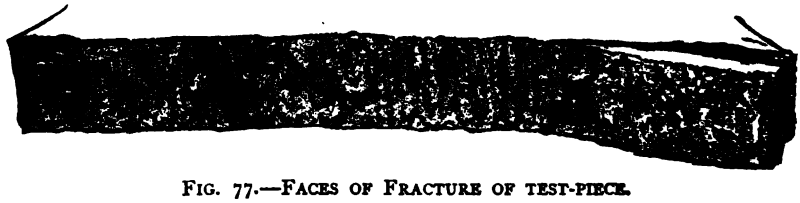


FIG. 77.—FACES OF FRACTURE OF TEST-PIECE.

The Tenacity of Copper varies greatly with chemical and physical properties. Rolled and forged metal from well fluxed castings or ingots is stronger than any castings, and becomes stronger with rolling or drawing.

Major Wade * found the tenacity of Lake Superior *cast* copper to range from 22,000 to nearly 28,000 pounds per square inch (1,547 to 1,968 kilog. per sq. cm.), averaging above 24,000 pounds (1,705 kilogs.). Egleston gives the tenacity of both Lake Superior and Ore Knob (N. C.) copper as above, 30,000 pounds per square inch (2,109 kgs. per sq. cm.).

Anderson † gives the figures for the tenacity of copper, which, in round numbers, are as below—ordinary copper is compared with that fluxed with phosphorus:

TENACITY OF COPPER.

	PHOS.	TENACITY, T.	
		Lbs. per sq. in.	Kilog. per sq. cm.
Copper, forged	.....	34.000	2,390
" cast	.....	19.000	1,336
" "	.....	25,000	1,758
" forged	0.015	38,000	2,671
" "	0.02	45,000	3,164
" "	0.03	48,000	3,374
" "	0.04	50,000	3,515

The effect of fluxing with phosphorus is here very plainly shown and amounts to an average increase of tenacity of 4,000 pounds per square inch (2,812 kilogs. per sq. cm.) for each one per cent. added up to four per cent.

* Metals for Cannon, 1856.

† Strength of Materials.

SHEARING.

Angle formed by shear-blades, 3 degrees.

Sheet Metals.

IRON.		COPPER.		BRASS.		STEEL, PUDDLED.	
Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.
In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.
1.0*	144,000	.207	11,196	.05	540	.24	14,020†
.615	53,440	.238	6,007	.042	423	.24	14,930‡
.510	39,150	.204	4,820	.035	313	...	.....
.404	25,970	.150	3,676	.025	220	...	.....
.283	15,715	.09	2,200	.024	200	...	.....
.183	10,390	.064	1,006	....	...	...	.....
.104	4,200	.05	552	....	...	...	.....
.057	2,180	.02	113	....	...	...	.....

Bolts.

IRON.				COPPER.		BRASS.	
Diameter.	Pressure.	Diameter.	Pressure.	Diameter.	Pressure.	Diameter.	Pressure.
In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.
1.142	35,410	.697	13,979	.943	18,460	1.110	29,790
1.040	30,707	.585	10,593	.906	13,872	.905	22,386
.945	24,057	.447	5,543	.775	11,310	.779	17,976
.812	19,688	.320	3,093	.635	8,218	.648	11,648

The shearing resistance of copper is usually given in office hand-books as from 22,000 to 30,000 pounds per square inch (1,420 to 2,109 kilogs. per sq. cm.). Its value may be taken as the same as in tension and as subject to the same variations.

The work done in shearing copper is, according to Haswell, measured, for punched holes, by

$$W = 96{,}000\, d\, t,$$

in which W is the work in foot-pounds, d the diameter of the hole, and t the thickness of the sheet in inches.

Resistance to Compression varies with copper, as with all ductile and malleable metals, more with variation of form of test-piece and method of application of the stress than with the ordinary modifications of composition and of form produced in manufacture, as ingots, sheets, rods, bolts,

* The cutters were parallel; the bar 3 inches wide.

† With oil. ‡ Without oil.

etc. The application of a crushing force to a test-piece of standard size and proportions first reduces it to the barrel-form, then to that of a flat cheese-shaped mass, and finally to a sheet of which the *total* resistance to compression increases indefinitely as its area becomes greater by flow. The compression stress thus increases from about that required to produce rupture by tension to that demanded to produce free flow when the *intensity* of the stress is a maximum; and its total amount is limited only by the area of the sheet produced. The intensity, C, of resistance to compression is usually incorrectly stated, without limitation, as about 100,000 pounds per square inch (7,030 kilogs. per sq. cm.) for rolled or forged, and 120,000 pounds (8,436 kilogs.) for cast copper. The results of experiments of the Author, presently to be given, indicate that good cast copper, in cylinders of three diameters length, will exhibit a resistance which may usually be reckoned up to a compression of one-half or more, as

$$C = 145{,}000 \sqrt[3]{e}, \text{ nearly,}$$

$$C_m = 10{,}000 \sqrt[3]{e}, \text{ nearly,}$$

where C and C_m are the resistance to compression in British and metric measures, and e is the compression in unity of length, the resistance being reckoned per unit of original section. But the volume of the piece remaining practically unaltered, the section is increased very nearly in proportion to the compression, and the resistance will thus become

$$C^1 = 72{,}000 \sqrt[3]{e}, \text{ nearly,}$$

$$C_m = 5{,}000 \sqrt[3]{e}, \text{ nearly,}$$

when reckoned per unit of area of section actually.

The effect of impact on the tough metals having no definite limit of elasticity is modified by the velocity of the striking mass, and by the inertia of the piece attacked, to an extent, as yet, not fully determined. The experiments of Kick indicate a considerable increase of total work of resistance, when the piece is deformed in this manner, over that noted when the compression is produced slowly by steady pressure. The experiments of the Author also indicate that this work is the greater, with soft and malleable metals, as the velocity of action is increased. The real efficiency of the press, as above, is thus probably somewhat greater than the figures obtained would indicate.

The above facts were well shown in experiments by the Author on the power of drop-hammers, in which the work done in crushing copper cylinders was compared with that required under the slower action of the hydraulic press.

Copper, Subjected to Transverse Stress, is probably always to be considered as belonging to the second class of materials treated of as above, and as more correctly represented by the equation here given below, than the usually adopted equation following:

$$M^1 = R^1 \int_o^b \int_o^{d_1} y\, dy\, dx, \text{ and } Fl = 2\,\pi\, s, \int_{r_0}^{r_1} r^2\, dr,$$

instead of

$$M = \frac{R}{d_1} \int_o^b \int_o^{d_1} y^2\, dy\, dx, \text{ and } Fl = \frac{2\,\pi\, s_1}{r_1} \int_{r_0}^{r_1} r^3\, dr,$$

the former of which, for rectangular bearers and solid shafts, would become, were $T = C$,

$$M^1 = \frac{1}{4} R^1 \frac{b\, d^2}{l}; \qquad Fl = 2.2\, s_1 r^3,$$

instead of

$$M = \frac{1}{6} R \frac{b\, d^2}{l}; \qquad Fl = 1.6\, s_1 r_1^3.$$

The values of T and C are not, however, the same, and the differential expression must be integrated for the two sides of the bar separately.

Cast copper, tested by transverse stress, when of fair quality should give figures equal to, or exceeding, those obtained in the record which follows:

TEST OF BAR OF CAST COPPER.

No. 55.—Material: Copper, cast in iron mould.—Dimensions: Length between supports, $l = 22''$; breadth, $b = 0.985''$; depth, $d = 0.970''$

LOAD.	DEFLECTION.	SET.	MOD. ELASTICITY.	LOAD.	DEFLECTION.	SET.	MOD. ELASTICITY.
20	0.0033	.....	.....	480	0.4088	.....	.....
40	0.0075	.....	15,792,947	500	0.4855	.....	.....
80	0.0176	.....	13,459,739	5	.....	0.3619	.....
100	0.0224	.....	13,219,331	540	0.6343	.....	.....
5	.....	0.0001	.....	580	0.8378	.....	.....
140	0.0337	.....	12,301,425	Ruptured.	.....	.....	.....
180	0.0477	.....	11,174,068	580	0.8653	.....	.....
200	0.0552	.....	10,728,725	680	1.46	.....	.....
5	.....	0.0095	.....	720	1.74	.....	.....
240	0.0674	.....	10,540,763	800	2.39	.....	.....
280	0.0910	.....	9,111,146	840	2.85	.....	.....
320	0.1176	.....	.....	860	3.23	.....	.....
360	0.1553	.....	.....	Supports slid out. Bar bent.			
400	0.2057	.....	.....	Breaking load, P = 860 pounds.			
5	.....	0.1114	.....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 30{,}621.$			
440	0.2883	.....	.....				

The modulus of rupture for good cast copper should thus exceed 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), but may be expected to vary between 20,000 and 40,000 (1,406 and 2,812 kilogs.) with variations in the soundness and quality of the metal.

Rolled Copper, as tested by the Author, when of good quality and sound, may give values of the modulus of rupture as high as $R = 60{,}000$ pounds per square inch (4,218 kilogs. per sq. cm.), and sometimes exceeds this figure, one test under the eye of the Author, having given $R = 60{,}900$ $R_m = 4{,}281$.

The Modulus of Elasticity of Copper is almost invariably obtained by calculation from the results of transverse tests, using the expressions,

$$E = \frac{Pl^3}{48SI}, \quad E = \frac{Pl^3}{4Sbd^3},$$

for the general case and for rectangular sections, respectively,* when the weight of the bar may be neglected, as is the case with metal test-pieces, usually. By reference to the records of tests of cast copper already described in this treatise, it will be seen that this modulus may vary, with even the variation of light loads, from 10 to 15 million pounds per square inch (703,000 to 1,054,500 kilogs. per sq. cm.), and the same differences are observable as a consequence of varying quality. The higher values obtained in any one test are the most probably correct, and it may be assumed that the modulus of elasticity of copper approaches 15,000,000 pounds per square inch (1,054,500 kilogs. per sq. cm.), as the metal is obtained in a state approximating purity and soundness. Usual values are two-thirds to three-fourths these.

Some authorities give values exceeding the maximum, as above, by 20 per cent., but such figures are not to be expected in the ordinary work of the engineer.

Forged and wire-drawn copper, as tested by Wertheim, gave the following values of this modulus:

	KILOGS. PER SQ. CM.
Copper, hard-drawn	1,245,000
" "	1.254,000
" annealed	1,052,000
" "	1,254,000

or very nearly 18,000,000 pounds per square inch for hard-drawn, and 20 per cent. less, in some cases, for annealed wire.

* See Part II., p. 499, § 268, M. of .E.

Copper Subjected to Torsion is found to exhibit the same variation of resistance with quality and physical structure that has been seen in other methods of test. The experiments of the Author give values of s_1 in the equations for total resistance, above, ranging between 20,000 and 40,000 pounds per square inch (1,406 and 2,812 kilogs. per sq. cm.), the lower figure for cast copper of ordinary soundness, and the higher for good forged or rolled copper. Thus for the two cases, it may be assumed that copper shafts will break under load when

$$d_1 = \sqrt[3]{\frac{Fl}{4{,}000}}, \text{ or } d_1 = \sqrt[3]{\frac{Fl}{8{,}000}}$$

accordingly as they are made of cast or worked copper, when the units employed are inches and pounds, or

$$d_{1m} = \sqrt[3]{\frac{Fl}{300}}, \text{ or } d_{1m} = \sqrt[3]{\frac{Fl}{400}}$$

when the units are metric.

Copper is seldom subjected, however, to any other than tensile stresses. It would probably be more correct to use the expressions given for tough metals than the above, making the true value of $s_1 = 15{,}000$ to 30,000 pounds.

Results of all Tests of Cast Copper made for the Committee on Alloys of the U. S. Board being collected, rejecting all tests of samples known to be defective, the following figures were obtained. It will be remembered that these experiments were made with ordinary commercial metals melted and cast in the usual way and purposely without other precaution than is usually taken in every-day foundry work. Much higher figures, as has been seen, may be attained.

AVERAGE OF TESTS OF COPPER.

	TRANSVERSE TESTS.				TENSILE TESTS.				TORSIONAL TESTS.			
	Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Tenacity per square inch of— Original section.	Tenacity per square inch of— Fractured section.	Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fibre.
Brit. Meas.	765	26,357	0.232	10,076,756	0.0628	23,118	26,817	0.491	118.06	41.79	0.354	0.2630
Metric	348	1,853	0.232	708,396	0.0628	1,625	1,885	0.491	16.4	5.8	0.354	0.263

The composition of these bars of copper was found to be:

ANALYSES OF TURNINGS FROM FOUR BARS OF COPPER.

	NO. 1.	NO. 30.	NO. 53.	NO. 57.
Metallic silver.....	0.035	0.014	0.015	0.063
Metallic iron.....	0.020	0.014	0.035	0.014
Metallic zinc.....	0.014	0.057	0.016	None.
Metallic lead.....	Trace.	Trace.	None.	Trace.
Metallic bismuth	None.	None.	None.	None.
Metallic arsenic.....	None.	None.	None.	None.
Metallic antimony	None.	None.	None.	None.
Suboxide of copper	12.086	3.580	6.730	1.620
Metallic copper.....	87.900	96.330	93.200	98.330
Insoluble matter.....	.....	.....	.....	0.005
Carbon	None.	.....	.....	.....
	100.055	99.995	99.996	100.032

The Strength of Tin, as obtained in the market, is variable with the brand, the purity, the soundness, and density of the metal, with the temperature and the velocity of distortion and rupture, and with other variable conditions, as

is the strength of copper, but in less degree so far as it depends upon the skill and care of the metallurgist. It is less subject to injury by the presence of deleterious elements, and is less liable to become unsound in melting and casting.

Mallet obtained a tenacity of 5,600 pounds per square inch (3,936 kilogs. per sq. cm.), Rennie about 5,000 pounds per square inch (3,515 kilogs. per sq. cm.), and the Author has obtained figures for the U. S. Board, and in other experiments, ranging from 2,000 to 6,000 pounds per square inch (1,406 to 4,218 kilogs. per sq. cm.) for Banca and Australian tin of the following composition:

COMPOSITION OF TIN OF COMMERCE.

	INGOT BANCA TIN.	INGOT QUEENSLAND TIN.
Metallic iron	0.035	0.035
Metallic zinc	None.	None.
Metallic silver	.....	.....
Metallic arsenic	None.	Trace.
Metallic antimony	None.	None.
Metallic cobalt	.....	None.
Metallic bismuth	None.	None.
Metallic nickel	.	None.
Metallic lead	None.	0.165
Metallic manganese	.....	0.006
Metallic molybdenum	None.	None.
Metallic tungsten	.....	None.
Metallic copper	None.	None.
Metallic tin	99.978	99.794
Suboxide of copper	.....	.....
Carbon	.....	.....
Matter insoluble in aqua regia	Trace.	.....
	100.013	100.000

In casting tin in iron moulds, a difficulty was met with in the formation of surface "cold-shuts," producing an irregular section in bars of otherwise sound condition.

RESISTANCE TO COMPRESSION: CAST TIN.

No. 29 C.—Material: Banca tin, cast in iron mould.—Dimensions: Length, 2"; diameter 0.625".

LOAD.	COMP.	C.	COMP. PER UNIT.	
1,250	0.003	4,074	.0015	At 1,850 pounds (110 kilogs. per sq. cm.), the piece was observed to be bulging out on all sides, but still remaining vertical. At the end of the test the piece had a slight bend in one direction, and was increased in diameter to 0.85 and 0.89 inch in different parts of the length.
1,500	0.012	4,889	.0060	
1,750	0.043	5,704	.0215	
1,850	0.097	6,030	.0485	
1,900	0.158	6,193	.0790	
2,000	0.265	6,519	.1325	
2,000	0.473	6,519	.2365	
2,200	0.612	7,171	.3060	
2,300	0.729	7,497	.3645	
2,300	0.899	7,497	.4445	

With tin, as with copper, and all ductile metals, the resistance to compression per unit of original section increases indefinitely with progressing distortion, and probably attains a maximum, as reckoned per unit of momentary sectional area, when the intensity of stress becomes equal to the resistance to the metal to continuous flow.

Elastic limits are even less well defined with tin than with copper, and the resistance rises rapidly, at the start, as distortion commences and progresses. Resistance to compression is stated by Trautwine and Haswell as above 15,000 pounds per square inch (1,054 kilogs. per sq. cm.).

Tin under Transverse Test behaves much like copper, but it has less strength and even less elasticity. It is the best representative of the viscous class of metals, and, as will be seen in the chapter on conditions modifying strength of the non-ferrous metals, is peculiarly susceptible to variation of time of loading and rapidity of distortion. Tests of cast tin made by the Author for the government, as above, gave data of which the following is fairly illustrative:

CAST TIN IN TRANSVERSE TEST.

No. 29.—Material: Banca tin, cast in iron mould.—Dimensions: Length between supports, 22″; breadth, 0.993″; depth, 1.002″.

LOAD.	DEFLECTION, Δ.	SET.	MODULUS OF ELASTICITY. $E = \frac{l^3}{4 \Delta bd^3}(P+4)$	LOAD.	DEFLECTION, Δ.	SET.	MODULUS OF ELASTICITY. $E = \frac{l^3}{4 \Delta bd^3}(P+4)$
Pounds.	*Inch.*	*Inch.*		*Pounds.*	*Inch.*	*Inch.*	
3	0.0008	.....	.....	80h. in 5m	0.262	.....	.....
5	0.0032	.....	.....	5	.....	0.265	.....
10	0.0055	.....	.....	85	0.340	.....	.....
20	0.0095	.....	6,734,838	In 10 □	0.840	.....	.....
0	..	0.0047	.....	90	0.966	.....	.....
24	0.012	.....	6,218,983	90h. 10m.	1.199	.....	.....
30	0.015	.....	6,039,908	0	.....	1.255	.. .
35	0.017	.....	.....	100	1.360	.....	.....
0	.. ..	0.0055	.....	In 5 m.	1.624	.....	... .
40	0.021	.....	5,583,107	In 20 m.	2.124	.....	.....
0	.....	0.0095	.....	0	.....	2.065	.....
45	0.029	.....	.....	110	2.332	.....	... .
0	.....	0.015.	.....	In 10 m.	8.395	Bar bent and tray reached bottom of supports.	
50	0.041	.....	3,517,648				
0	.....	0.021.	.....				
60	0.062	.... .	2,750,622				
0	. ....	0.043.	.....				
70	0.104	.....	.....				
0	.....	0.082.	.....				
80	0.218	.....	1,026,752				

Crack observed on under side of bar extending across half its breadth.

Breaking load, 110 pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{l}{bd^2}(P+3) = 3,750.$

R_m (metric), = 262.9

Tests of Queensland and Banca tin, compared, stood as follows:

TRANSVERSE TESTS OF TIN.

Number.	MATERIAL.	Length between supports.	Breadth, *b*.	Depth, *d*.	Breaking load, *P*.	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2}$	Total deflection, Δ.	Limit of elasticity. Load.	Limit of elasticity. Parts of break-load.	Modulus of elasticity.	REMARKS.
		Ins.	*Ins.*	*Ins.*	*Pds*		*Ins.*				
28	Queensland tin..	22	1.038	1.023	150	4,559	3. +	4	.267	5,635,593	Bent.
29	Banca tin.....	22	0.993	1.002	110	3,740	8. +	3	.273	6,734,838	Bent.
	Mean of 2 bars..	.....	.....	.....	130	4,150	....	....	.270	6,185,210	

Queensland tin proved very good, showing a somewhat greater strength by transverse and torsional test than Banca tin, but a less strength by tension. The transverse strength probably appears higher than it should be, both on account of different methods of test, the Banca tin being tested by dead loads and the Queensland tin by platform-scale, and on account of a perceptible flaw in the centre of the Banca bar.

In the test of No. 29, as above, a load of 40 pounds produced a set of 0.0095 inch, and the elastic limit appeared to be reached at about 30 pounds. At 80 pounds a crack was observed on one of the edges on the under side of the bar, which gradually opened but did not increase in length. At 110 pounds the bar sank gradually, the deflection increasing more than 6 inches in ten minutes. The bar was finally broken by repeated bending, and showed that the crack above mentioned was produced by an imperfection in the casting, about one-fourth of the surface, or that portion in which the crack was observed, showing radiated lines of cooling and the remainder the close pasty appearance peculiar to tin ruptured by bending. The crack weakened the bar, and the final bending was resisted by but little more than three-fourths of the section.

Major Wade found the tenacity of Banca tin used in making U. S. Army ordnance to be 2,122 pounds per square inch (148 kilogs. per sq. cm.); its density was 7,297.

The Modulus of Elasticity of Tin is stated by Tredgold at 4,600,000 pounds per square inch (285,400 kilogs. per sq. cm.) for cast metal, by Molesworth at same figure nearly, and is found by the Author to vary up to nearly 7,000,000 pounds (492,000 kilogs., nearly). Some of the figures obtained are given in the records of transverse tests of cast tin already referred to.

No values have been found for other forms of this metal. Tin is, however, probably less affected by the form in which it enters the market than other common metals, and the moduli here given may be accepted for general use as substantially accurate.

Tin in Torsion, as tested by the Author, gives

figures of which the following, from the Report of the U. S. Board, may be taken as fairly representative:

TORSIONAL TESTS OF TIN.

Averages of Results calculated from Autographic Strain-Diagram.

Number.	MATERIAL.	Area of diagram.	Angle of torsion.	ORDINATES OF DIAGRAM.		TORSIONAL MOMENT.		Extension of exterior fibre.	Resilience.	No. of pieces averaged.
				Maximum.	At elastic limit.	Maximum.	At elastic limit.			
		Sq. ins.	*Degrees.*	*Ins.*	*Ins.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*	
58	Queensland tin ..	42.78	691.0	0.73	0.22	13.15	4.36	2.9029	208.48	3
29	Banca tin	21.26	556.8	0.48	0.13	12.75	5.78	2.1975	105.45	4
	Mean (British) ...	32.02	623.9	0.61	0.18	12.95	5.07	2.5502	156.97	....
	Metric	20.6	623.9	1.6	0.46	1.8	0.7	.....	.....	....

The Queensland tin showed an extraordinary ductility in the torsional tests, one of the pieces twisting through an angle of 818 degrees, or more than 2¼ turns before breaking. This represents an elongation of a line of particles parallel to the axis on the surface of the cylindrical portion of the test-piece from one inch to 4.57 inches.

The average of all tests of tin is given in the following:

AVERAGE RESULTS OF TESTS OF TIN.

TRANSVERSE TESTS.				TENSILE TESTS.				TORSIONAL TESTS.				
Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Tenacity per square inch of—		Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fibre.	Resilience.
					Original section.	Fractured section.						
130	4,150	.270	6,185,210	.3551	3,130	.....	.476	12.95	5.07	.392	2.5502	156.97

The Strength of Zinc has been determined by but few investigators, and, like that of all other useful metals except iron and steel, is a subject of which comparatively little is known by the engineer.

Cast zinc is stated to have a tenacity of about 4,000 pounds per square inch (281.2 kilogs. per sq. cm.), and a resistance in compression of ten times that amount. Stoney states the tenacity at nearly 3,000 pounds (211 kilogs.) cast, and Trautwine gives for sheet-zinc and zinc wire 16,000 and 22,000 pounds per square inch (1,124.8 and 1,546.6 kilogs. per sq. cm.), respectively. The modulus of elasticity is given by Wertheim and by Tredgold at from 12,000,000 to nearly 14,000,000 pounds per square inch (843,600 to 984,200 kilogs. per sq. cm.), the value being higher for cast zinc. The Author has obtained much smaller figures.

Pure zinc, like pure tin, is never used alone, by the engineer, for purposes demanding strength and toughness. The values of the several moduli are given as of interest, however, and for comparison.

Samples of *cast zinc* tested by the Author show variable tenacity, the figures ranging between 4,500 and 6,500 pounds per square inch (2,847 to 4,253 kilogs. per sq. cm.), or considerably above those given by earlier investigators. All the zinc thus tested by the Author was very pure, and made from New Jersey calamine. The effects of varying time and rapidity of strain are observable in zinc, as in tin, and are the same in kind; they will be described later.

Zinc is much less ductile than tin.

The resistance of zinc to compression varies with the degree of reduction, and, as tested by the Author, was about 22,000 pounds per square inch (1,547 kilogs. per sq. cm.) when the compression amounted to one-tenth the original height of test-piece in pieces three diameters long, and one-half greater for a compression of one-third. Zinc is weaker under compression than any copper-zinc alloy.

Zinc has no defined elastic limit, but an apparent elastic limit in compression was recorded at 5,000 pounds per square inch (352 kilogs. per sq. cm.).

Records of Test of Zinc are given below, as reported to the U. S. Board.

TENACITY OF CAST ZINC.

Length, 5"; diameter, 0.798".

LOAD.	TOTAL EXTENSION.	SET.	PER CENT. ELONGATION.	REMARKS.
800	0.0011	.....	0.02	
1,200	0.0024	.....	0.02	Diam. fractured.
1,600	0.0034	.....	0.07	Section, 0.796".
2,000	0.0051	.....	0.10	Tenacity, 6,300 pounds
3,000	0.0097	.....	0.19	per square inch (4.429
4,000	0.0157	.....	0.31	kilogs. per sq. cm.).
200	.....	0.0006	....	
5,000	0.0206	.....	0.41	
6,000	0.0240	....	0.48	
6,300	Broke.	.....	....	

COMPRESSION OF CAST ZINC.

Length, 2"; diameter, 0.625".

LOAD.		COMPRESSION.	LOAD.		COMPRESSION.
Total.	Per sq. in.	Per cent.	Total.	Per sq. in.	Per cent.
1,000	3,259	0.15	8,000	26,076	12.15
2,000	6,519	0.55	9,000	29,335	17.15
3,000	9,778	1.85	10,000	32,595	20.60
4,000	13,038	3.40	10,000	"	21.80
5,000	16,297	5.10	10,500*	34,225	24.40
6,000	19,557	7.20	Resistance fell to		
7,000	22,816	10.65	10,000	32,595	33.35

* Continued one minute.

CAST ZINC LOADED TRANSVERSELY.

LOAD.	DEF.	SET.	E.	REMARKS.
20	0.0101	...	.....	
40	0.0171	...	6,698,725	
60	0.0246	...	6,927,556	Modulus of rupture,
80	0.0324	...	6,984,644	R = 7,540 pounds per
100	0.0424	...	6,655,180	sq. in. (5,300 kilogs.
120	0.0506	...	6,680.965	per sq. cm.).
140	0.0616	...	6,395,032	Most probable value
3	.....	0.0	.....	of E = 6,900,000
160	0.0753	...	5,973.588	E_m = 428,130.
180	0.0906	...	5,581,549	
200	0.1244	...	1,797,132	
Broke.	.....	...	.....	

TESTS OF CAST ZINC BY TORSION.

Length, 1"; diameter, 0.625".

NO.	AREA DIAGRAM.	ANGLE.	MAX. ORDINATE.	MAX. MOMENT.	EXTEN. EXTER. FIBRE.
21 A	19 63	123°	2.15	37.83	0.2042
21 C	18.81	129	2.07	36.55	0.2227
21 D	17.24	151	1.95	34.42	0.2955
21 B	18.13	163	2.15	37.83	0.3380

Other Metals than those already described have been made the subject of very few experiments and the data obtainable are very unsatisfactory. The *alloys* of the three principal non-ferrous metals are made the subject of succeeding chapters.

Lead has a tenacity which is reported by Haswell as:

	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Lead, cast.....	1,800	116.5
" milled.....	3,320	233.4
" wire.....	2,580	181.4

In compression the resistance is stated to be 7,700 pounds

per square inch (541 kilogs. per sq. cm.) and the modulus of elasticity is given as 720,000 lbs. (49,350 kilogs.). Wertheim, however, obtains a value of 21,500,000 pounds per square inch (175,750 kilogs. per sq. cm.). Trautwine gives, for tenacity:

	LBS. PER SQ. IN.	KILOGS. PER. SQ. CM.
Lead, cast	1,800 to 2.400	116.5 to 168.7
" pipe	1,700 to 2 240	119.5 to 157.5
" wire	1,600	112.5
" sheet	1,925	155.5

as collated from various older experiments, and a resistance to compression agreeing with Haswell.

The strength of lead pipe, as obtained in market, has, when tested, been found variable. The best results noted by the Author * indicate a tenacity of the metal exceeding one ton per square inch (2,240 lbs.; 157.5 kilogs. per sq. cm.). Comparing the results of a number of experiments to obtain a value of p in Clark's formula:

$$T = \frac{p}{log\ R}; \qquad p = T\ log\ R;$$

in which T is the tenacity, p the pressure, and R the ratio of external and internal radii, a mean value of T was found to be 1.4 tons per square inch (220.5 kilogs. per square cm.). The minimum value was three-fourths as great. It is probable that a much lower pressure, long continued, would have burst these pipes.

The thickness of lead pipe is frequently determined by the rule:

$$t = 0.0024\ n\ d + 0.2,$$

in which t is the thickness in inches, n the pressure in atmospheres and d the internal diameter in inches.

* Lond. Engineer; Nov. 16, 1883, p. 378.

Antimony has a tenacity of about 1,000 pounds per square inch (70 kilogs. per sq. cm.), and *bismuth* of three times that amount. *Gold* is a moderately strong metal, with a tenacity, cast, of 20,000 pounds per square inch, and of 30,000 in wire (1,406 to 2,109 kilogs. per sq. cm.). *Silver* is reported to be about equally strong (?) in the two forms, having a tenacity of 40,000 pounds per square inch (2,812 kilogs. per sq. cm.), according to Baudrimont. Platinum has a strength of from 30,000 to above 50,000 pounds (2,109 to 3,515 kilogs.). Nickel, tested by the Author, exhibited tenacities of from 50,000 to 54,000 pounds per square inch (3,515 to 3,543 kilogs. per sq. cm.), elongating about 10 per cent. Palladium, tested by Wertheim, had a tenacity equal to that of nickel. It is questionable whether any of these metals have a true elastic limit.

Wertheim on Elasticity.—Wertheim gives the following as the densities, atomic weights, and products of the two, and also the tenacities and sound-conductivity of several metals:

	S. G.	AT. WT.	S. G. × A. W.	RESISTANCE TO RUPTURE PER MILLIMETRE.		Coefficient of elasticity (Tredgold).	Rapidity of sound (Chladni).
				By extension (Guyt-Morveau).	By compression (Rennie).		
Lead	11.352	12.94498	0.8769	0.022	1.45	600	....
Tin	7.285	7.35294	0.9907	0.063	6.20	3.200	7.5
Gold	19.258	12.43013	1.5493	0.274	....	.....	....
Silver	10.542	6.75803	1.5599	0.341	....	.....	9.0
Zinc	6.861	4.03226	1.7015	0.199	....	9.600	....
Platinum	21.530	12.33499	1.7454	0.499	....	.....	....
Copper	8 850	3.95695	2.2365	0.550	38.55	.....	12.0
Iron	7.788	3.39205	2.2959	1.000	....	20.000	17.0

He infers a general variation of cohesion with change of intramolecular distances, and obtains his data from experiments upon fifty-four binary alloys and nine ternary alloys. He gives the following values of moduli of elasticity:

MODULI OF ELASTICITY OF METALS.

	LBS. PER SQ. IN.	KILOGS. PER SQ. CM.
Lead	2,500,000	176,000
Cadmium	7,700,000	492,000
Gold	11,500,000	808,500
Silver	10,000,000	703,000
Palladium	17,000,000	1,195,000
Platinum	24,000,000	1,687,000

Bischof's Method of Test to determine the purity and economic value of metals consists in making strips of a definite and standard size and subjecting them to repeated bending. The purer the metal, as a rule, the greater the number of changes of form required to produce fracture. Zinc, for example, was found to withstand 100, 54 or 19 bendings accordingly as it was pure zinc, best commercial spelter or the lowest quality. The ill effect of the introduction of 0.00001 tin, or of 0.0004 cadmium is perceivable even more certainly than by analysis.

Metals which do not alter by remelting, as tin or zinc, are melted in crucibles, with continual stirring and then cast in ingot moulds, 12 cm. long, 1.3 cm. square at the top and 0.3 cm. square at the bottom, 40 or 50 grammes being taken for a test, or 60 grammes for lead. The bars thus made are rolled to the desired thinness, annealed and tested. Metals, as brass, bronze or copper, which are liable to change in fusion, are rolled from the commercial form, with repeated annealing. The strips tested by Bischof were 13 cm. (4 inches) long, 0.7 cm. (2 inches) wide and of such thickness that they weigh as follows: Copper, 17; brass, 16; tin and zinc, 15; lead, 25; iron and steel, 12 grammes. They were tested in a "metallometer," in which they could be bent conveniently to any angle. Repeated flexure and reflexure through an angle of 67½ degrees was found best adapted to bring out the quality of the metal.

CHAPTER XIII.

STRENGTH OF BRONZES AND OTHER COPPER-TIN ALLOYS.

The Bronzes—under which name are included the principal alloys of copper and tin, and a few special compositions—vary, in strength, elasticity, ductility and hardness, with variations of composition to such an extent that they find application in an immense number of the engineer's constructions, their character and chemical constitution being adjusted to his needs. The most common of these alloys is "gun-bronze," which consists, usually, of 90 parts copper, 10 of tin, or 89 copper, 11 tin. Such bronze has a strength which will depend greatly on the soundness of the castings and purity of the constituents of the alloy, but which often may exceed 50,000 pounds per square inch (3,515 kilogs. per sq. cm.) in tension.

Bronze used for journal-bearings in machinery is made harder or softer, according to pressure sustained, the composition approaching usually that of gun-bronze, and ranging from copper, 7; tin, 1; to copper, 11, tin, 1; *i.e.*, copper, 87.5; tin, 12.5, to copper, 91.67; tin, 8.33. A little zinc or lead added slightly softens it. Packing rings for steam engines are made of still softer and more ductile bronze—copper, 92, to copper, 96. These alloys have been very fully described elsewhere, and this chapter is devoted entirely to the consideration of their strength, ductility, elasticity and density.

Gun-bronze, according to the "Ordnance Manual," should have a tenacity of 42,000 pounds per square inch (2,826 kilogs. per sq. cm.), and a specific gravity of 8.7.

In Major Wade's report on "Experiments on Metals for Cannon," 1856, are given records of a number of tests of gun metal.

Specimens of metal from 83 "gun-heads" (the upper part

of the casting is always deficient in strength) gave an average result of 29,655 pounds per square inch (2,085 kilogs. per sq. cm.), the highest figure being 35,484 and the lowest 23,529 pounds. This alloy was copper, 9; tin, 1.

Small bars made of gun metal gave higher figures. One set of 16 bars gave an average result of 42,754 pounds (3,006 kilogs. per sq. cm.), and another similar set an average of 41,284 pounds (2,902 kilogs. per sq. cm.), the lowest figure of the 32 specimens being 23,854 pounds and the highest 54,544 pounds. Five of the specimens gave more than 50,000 pounds (3,515 kilogs. per sq. cm.), and only three less than 30,000 pounds (2,109 kilogs. per sq. cm.).

The average of 12 gun-heads was one-half that obtained from the small sample bars cast with the guns.

A sample of very inferior quality fell below 18,000 pounds (1,265 kilogs. per sq. cm.).

Major Wade found the quality of bronze ordnance enormously irregular and uncertain, and considered it very important that a more reliable method of manufacture should be found.

The tenacity of gun-bronze thus depends greatly upon the method of manufacture, of casting, and of cooling. By careful handling it has been given a tenacity, in ordnance, exceeding, even, 60,000 pounds per square inch (4,218 kilogs. per sq. cm.), and the Author has obtained small bars still stronger. Bronze ordnance of large size has been made here and in Europe with success; it is, however, very liable to be irregular in composition and physical character, and the uncertainty always felt in regard to its condition is an element which enters into the question of its use for any purpose.

Continual use of ordnance is thought to lead to a separation of the tin from the copper, and to final destruction. The gases of powder sometimes corrode the metal badly.

The Modulus of Elasticity of gun-bronze is given by Tredgold at 10,000,000 pounds per square inch (703,000 kilogs. per sq. cm.), and this figure is confirmed by the experiments of the Author as given later, but it is subject to great variations with the condition of the metal.

Manganese Bronze is another valuable alloy. That used in the construction of torpedo boats for the British navy was supplied under a contract calling for a tenacity of 26 to 31 tons per square inch (4,094 to 4,882 kilogs per sq. cm.), and an elongation of 20 per cent.

This sheet bronze was from $\frac{1}{16}$th to $\frac{1}{8}$th inch (0.16 to 0.32 cm.) thick (No. 9 to No. 18 B. W. G.), and sustained 29 to 30 tons (4,567 to 4,725 kilogs.), stretching 25 to 35 per cent., and bending cold to a radius equal to their thickness.

Manganese bronze, tested at the Royal (British) Gun Factory at Woolwich, England, by tension, gave the following figures, as reported to the Admiralty:

TENACITY OF MANGANESE BRONZE.

(Sheet Metal; Rods and Bolts.)

	NOS.	LOADS				ELONGATION.	
		Yielding.		Breaking.			
		Tons per sq. in.	Kgs. per sq. cm.	Tons per sq. in.	Kgs. per sq. cm.	Per cent.	
Bars and Rods.	4,766	14.0	2,204	24.3	3,817	8.7	Cast in metal mould.
	4,767	12.6	1,984	29.0	4,567	31.8	Ditto and forged.
	4,768	14.0	2,204	22.1	3,480	5.5	Ditto.
	4,769	13.2	2,079	28.8	4,535	35.3	Ditto and forged.
	4,770	16.8	2,645	23.6	3,717	3.8	Cast in metal mould, slight flaw in specimen.
	4,771	12.0	1,890	30.3	4,772	25.7	Cast in metal mould and forged.
							ROLLED RODS.
	6,536	11.0	1,732	29.0	4,567	44.6	Mild, for ships' bolts and rivets.
	6,545	16.6	2,615	30.7	4,835	20.7	High, for Engineers' bolts, pump rods, etc.
	6,546	14.6	2,299	30.0	4,725	26.2	Medium.
	6,547	34.4	5,417	39.6	6,237	11.6	Cold rolled.

AREA OF SPECIMENS, 0.133 INCH. LENGTH OF BREAKING PART, 2 INCHES.

Plates.	7,364	13.8	2,173	28.57	4,504	28.7	Pulled in direction of fibre.
	7,365	14.06	2,205	28.46	4,488	23.2	Across fibre.
	7,369	14.06	2,205	30.13	4,740	47.8	With fibre.
	7,372	14.8	2,331	30.78	4,850	34.1	Across fibre.
	7,374	26.7	2,630	30.1	4,740	28.8	With fibre.

The Copper-Tin Alloys, which, as has been stated, furnish a very large number of the best bronzes and engineers' compositions, and which are extensively used in every department of construction and the arts, had never been systematically studied until the investigation was made by the U. S. Government Board upon a plan prepared, proposed, and carried out at the request of that Board, by the Author. Earlier investigations had been confined to a few familiar compositions, and it was only when appropriations made by the Congress of the United States could be applied to such a research that it became possible to determine the method of variation of strength, elasticity, and ductility, and of specific gravity, and other properties, with variation of composition throughout all the possible proportions of copper and tin alloys. In the research to be described the principal assistant employed by the Author was Mr. William Kent.

Final Results.—The following table exhibits the results of the whole investigation in a compact form which permits ready comparison of data.

The average results obtained by test of the copper-tin alloys, enable the engineer to reach tolerably definite conclusions relative to their value in construction. The results are given as obtained by the four principal methods of stress. They are very variable, and this variability is due not only to the variation of composition of the alloys, but also to their differences of physical structure, and is, therefore, to some extent, accidental.

General conclusions may, nevertheless, be deduced and the principal facts revealed by test, and these conclusions are also most unmistakably exhibited by the diagrams presented in this and preceding articles.

The figures given by the tests have been plotted in the form of curves having for their ordinate the resistance observed and for their abscissas the distortion of the given test-piece. These curves exhibit the method of variation of resistance with progressing change of form, and constitute "strain diagrams" which exhibit to the eye every important quality of the material.

ALLOYS OF COPPER AND TIN.

Summary of Average Results.

NUMBER.	ATOMIC PROPORTION.	COMPOSITION OF ORIGINAL MIXTURE.		MEAN COMPOSITION BY ANALYSIS.		MEAN SPECIFIC GRAVITY.	TESTS BY TRANSVERSE STRESS.					TESTS BY TENSILE STRESS.					COMPRESSION TESTS.		TESTS BY TORSIONAL STRESS.				
							Modulus of rupture.	Elastic limit, in parts, of breaking load.	Total deflection before breaking.	Resilience within a deflection of $\frac{1}{24}$ inches.	Modulus of elasticity.	Tensile strength per square inch of—		Elastic limit, percentages of breaking load.	Total elongation, in parts of original length.	Diameter of fractured section, percentages of original.	Crushing strength, pounds per square inch.	Amount of compression, percentages of original length.	Torsional moment.		Ductility.		Resilience.
		Copper.	Tin.	Copper.	Tin.							Original section.	Fractured section.						Maximum.	Elastic limit, percentages of maximum.	Angle of torsion.	Extension of exterior fibre.	
							In's.			*Ft. lbs.*		*Lbs.*	*Lbs.*						*Foot lbs.*				
1*	Cu.....	100.00	0.00	.....	.....	‡8.487	21,251	.346	2.306	114.8	13,986,605	12,260	12,987	.862	.0047	.96	39,000	.10+	65.66	.505	40.50	0.0255	37.71
30	Cu.....	100.00	0.00	.....	.....	8.791	29,848	.140	Bent	191.25	10,203,205	27,800	32,496	.518	.0647	.92	42,000	.10+	143.24	.353	153.00	0.3084	320.35
2	$SnCu_{96}$..	98.10	1.90	97.89	1.90	8.564	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	34,000	.10+	150.46	.248	317.50	1.0006	572.51
31*	.....	97.50	2.50	99.09	0.87	8.511	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	$SnCu_{48}$..	96.27	3.73	96.06	3.76	8.649	33,232	.350	Bent	239.68	13,739,654	32,000	42,692	.500	.1429	.86	42,000	.10+	156.93	.338	247.40	0.7031	599.96
4	$SnCu_{24}$..	92.80	7.20	92.11	7.80	8.694	43,731	.426	Bent	310.58	14,263,420	28,540	33,780	.666	.0553	.92	42,000	.10+	160.01	.383	125.60	0.2189	277.22
32	.....	92.59	7.50	94.11	5.43	8.684	38,659	.370	Bent	264.20	13,581,817	27,900	34,383	.502	.0743	.88	.....	.....	156.63	.333	187.25	0.4318	368.33
5	.....	90.00	10.00	90.27	9.58	8.669	49,400	.400	Bent	345.01	14,012,135	26,860	30,205	.586	.0360	.93	38,000	.10+	175.28	.414	114.50	0.1795	274.60
33	.....	87.50	12.50	88.41	11.59	8.648	60,403	.353	4.000	415.14	12,472,655	31,100	33,153	.675	.0356	.97	.....	.....	178.05	.385	70.75	0.0730	175.23
6†	$SnCu_{12}$..	86.57	13.43	87.15	12.73	‡8.681	.....	.....	2.291	155.70	.....	29,430	30,680	.680	.0333	.98	53,000	.10+	182.32	.446	100.00	0.1391	253.61
34	.....	82.50	17.50	82.70	17.34	8.792	67,930	.565	0.625	57.75	15,152,664	36,200	36,346	.....	.0071	1.00	.....	.....	198.06	.516	14.00	0.0032	35.85
7	.....	80.00	20.00	80.95	18.84	8.740	56,715	.657	0.492	44.30	13,304,198	32,980	32,980	.....	.0040	1.00	78,000	.10+	190.15	.623	16.30	0.0040	35.59
35	.....	77.50	22.50	77.56	22.25	8.917	29,926	1.00	0.101	5.62	15,149,535	24,650	24,650	1.00	.0054	1.00	.....	.....	153.96	.714	4.38	0.0003	6.46
8	$SnCu_8$..	76.32	23.68	76.64	23.24	8.565	32,210	1.00	0.191	8.17	13,495,122	22,010	22,010	1.00	.....	1.00	114,081	.0_05	122.13	1.00	3.40	0.0002	3.78
36	.....	72.50	27.50	72.89	26.85	8.925	9,512	1.00	0.043	0.57	16,387,041	6,493	6,493	1.00	.....	1.00	.....	.....	35.54	1.00	1.00	0.00003	0.89
9	.....	70.00	30.00	69.84	29.89	8.932	12,076	1.00	0.052	0.97	15,321,716	5,585	5,585	1.00	.....	1.00	146,676	.0350	17.38	1.00	1.50	0.00008	0.63
10	$SnCu_4$..	68.25	31.75	68.58	31.26	8.938	9,132	1.00	0.043	0.58	15,694,356	1,620	1,620	1.00	.....	1.00	.....	.....	.....	.....	.....	.....	.....

37	.....	67.50	32.50	67.87	32.10	8.907	9,477	1.00	0.032	0.58	14,896,691	2,536	2,586	1.00	.....	1.00	.....	.....	26.13	1.00	1.65	0.00009	1.08
31	.....	65.00	35.00	65.34	34.47	8.947	4,776	1.00	0.020	0.12	19,344,368	2,201	2,201	1.00	.....	1.00	84,747	.0285	16.44	1.00	0.75	0.00002	0.36
38	.....	62.50	37.50	62.42	37.48	8.956	2,907	1.00	0.019	0.17	.....	1,561	1,561	1.00	.....	1.00	.....	.....	19.20	1.00	0.50	0.00001	0.15
12	$SnCu_3$ ..	61.71	38.29	62.31	37.35	8.970	2,761	1.00	0.032	0.12	9,603,989	688	688	1.00	.....	1.00	39,114	.0175	7.06	1.00	1.00	0.00003	0.25
39	.....	57.30	42.59	57.88	42.05	8.781	3,732	1.00	0.021	0.12	.....	1,377	1,377	1.00	.....	1.00	.....	.....	8.60	1.00	0.50	0.00001	0.16
13	Sn_8Cu_{13}	56.32	43.68	56.70	43.17	8.682	2,126	1.00	0.010	0.01	14,693,513	1,455	1,455	1.00	.....	1.00	.....	... .	8.94	1.00	1.00	0.00003	0.41
40	.....	52.50	47.50	53.46	46.55	8.643	1,995	1.00	0.008	0.05	.....	.....	.....	.....	.....	.....	.....	.....	7.77	1.00	0.40	0.00001	0.08
14	$SnCu_2$ ..	51.80	48.20	51.62	48.09	8.580	3,877	1.00	0.040	0.23	.....	2,555	2,555	1.00	.....	1.00	.. ....	.....	13.54	1.00	1.00	0.00003	0.19
15	Sn_7Cu_{12}	47.95	52.05	47.61	52.14	8.442	3,600	1.00	0.017	0.07	17,039,130	1,525	1,525	1.00	.....	1.00	84,747	.0215	14.87	1.00	1.00	0.00003	0.28
41	.....	47.50	52.50	47.27	52.72	8.446	5,601	1.00	0.017	0.18	.....	2,407	2,407	1.00	.....	1.00	.....	.....	17.96	1.00	1.00	0.00003	0.34
16	Sn_3Cu_8..	44.63	55.37	44.52	55.28	8.312	4,776	1.00	0.026	0.15	16,823,869	3.010	3,010	1.00	.....	1.00	35,854	.0066	23.35	1.00	0.92	0.00003	0.53
42	.....	42.50	57.50	43.99	55.91	8.437	6,084	1.00	0.036	0.33	§9,824,600	2,098	2,098	1.00	.....	1.00	.....	.....	16.23	1.00	1.33	0.00006	0.60
17	Sn_2Cu_3..	41.74	58.26	42.38	57.30	8.302	7,172	1.00	0.042	0.25	23,238,907	3.910	3,910	1.00	.....	1.00	39,114	.0205	28.11	1.00	1.65	0.00007	0.60
18	Sn_8Cu_{13}..	39.20	60.86	38.37	61.32	8.182	8,400	1.00	0.060	0.46	12,302,353	2,820	2,820	1.00	.....	1.00	29,335	.0145	23.46	1.00	1.70	0.00005	0.42
43	.....	37.50	62.50	37.10	62.90	8.101	6,942	.500	0.080	0.76	10,673,961	2,400	2,400	.....	.....	1.00	.....	.....	12.70	1.000	1.50	0.00004	0.20
19	SnCu....	34.95	65.05	34.22	65.80	8.013	5,384	.625	0.043	0.25	11,041,901	3.371	3,371	.....	.....	1.00	19,557	.0555	16.56	1.000	1.87	0.00005	0.31
44	.....	32.50	67.50	30.76	69.19	7.931	7,178	.476	0.112	1.28	6,984,987	2,322	2,322	.....	.....	1.00	.....	.....	17.32	.977	2.63	0.00014	0.73
20	Sn_4Cu_9..	28.72	71.28	25.85	73.80	7.948	8,067	.583	0.121	1.53	9,982,832	1,648	1,648	.....	.....	1.00	17,927	.10+	20.97	1.000	2.34	0.00011	0.76
45	.....	27.50	72.50	26.63	73.17	7.915	11,128	.438	0.220	3.69	7,803,107	4,380	4,380	.....	.....	1.00	.....	.....	25.50	.985	3.17	0.00018	1.06
21	Sn_5Cu_9..	24.38	75.62	23.35	76.29	7.835	12,408	.378	0.269	5.33	11,520,262	6,775	6,775	.....	.....	1.00	.....	.....	41.50	.979	4.50	0.0003	2.25
46	.....	22.50	77.50	22.10	77.58	7.774	13,687	.300	0.405	8.78	8,474,849	5,000	5,014	.....	.0022	1.09	.....	.....	27.80	.951	7.38	0.0012	3.31
22	Sn_2Cu ..	21.18	78.82	20.25	79.63	7.770	10,019	.333	0.345	5.35	9,743,644	4,337	4,337	.....	.....	1.00	16,297	.10+	22.93	.930	5.69	0.0006	2.07
47	.....	17.50	82.50	16.70	83.23	7.690	10,288	.267	0.533	11.51	7,356,258	2,816	2,822	.....	.....	1.00	.....	.....	24.39	.784	10.62	0.0020	3 96
23	Sn_3Cu ..	15.19	84.81	15.08	84.62	7.657	9,063	.222	0.858	12.89	7,032,130	6,520	6,520	.844	.0067	1.00	6,519	.10+	22.80	.753	24.83	0.0092	9.05
48	.....	12.50	87.50	11.69	88.24	7.543	10,254	.200	1.076	21.42	7,901,458	3,798	3,825	.527	.0055	.99	.....	.....	24.86	.779	56.50	0.0471	22.93
24	Sn_4Cu ..	11.84	88.16	11.49	88.47	7.552	10,706	.250	Bent	76.72	10,403,101	6,380	6,627	.549	.0410	.98	10,104	.10+	23.24	.653	61.75	0.0703	23.45
25	Sn_8Cu ..	9.70	90.30	8.57	91.39	7.484	5,305	.250	Bent	43.72	7,965,988	6,450	7,594	.543	.0687	.92	.....	.....	22.98	.631	131.75	0.2347	43.85
49	.....	7.50	92.50	6.05	93.77	7.417	9,764	.207	Bent	73.79	7,969,719	6,096	8,121	.427	.2022	.87	.....	....	19.83	.556	178.00	0.4006	50.66
26	$Sn_{12}Cu$..	4.29	95.71	3.72	96.31	7.360	6,925	.190	Bent	39.75	8,613,200	4,780	6,804	.575	.1232	.84	.....	.....	22.83	.514	220.50	0.5677	76.28
50	.....	2.50	97.50	2.11	97.68	7.342	8,374	.240	Bent	63.64	6,692,585	5,600	12,397	.214	.4000	.68	.....	.....	15.75	.474	362.00	1.2189	80.15
27	$Sn_{48}Cu$..	1.11	98.89	0.74	99.02	7.305	3,964	.333	Bent	33.16	6,771,517	3.650	7,867	.....	.2279	.70	.....	.....	18.29	.448	387.50	1.3388	90.40
28	$Sn_{96}Cu$..	0.55	99.43	0.32	99.46	7.290	4,438	.300	Bent	29.94	9,398,659	4,475	13,223	.559	.3544	.58	.....	.....	16.47	.418	535.30	2.0879	125.99
29	Sn	0.	100	.....	.....	7.293	3,740	.273	Bent	29.79	6,734,838	3,500	.....	.476	.3551	.50	6,400	.10+	12.75	.453	556.75	2.1975	105.45

* Defective bar. † Defective transverse bar.

‡ Specific gravity of turnings of ingot-copper, 8.874; specific gravity of turnings of No. 6 A, 8,943.

§ Short bar.

Strain-Diagrams, obtained from tests determining tenacity of the bronzes, are given in the accompanying figure as derived from experiments upon the first series of copper-tin alloys, No. 1, pure copper, to 29, pure tin, inclusive. The curves marked A are from the upper end of the bar and B from the lower end.

These curves may evidently be divided into three classes: viz., those which are very rigid and brittle, as 7 A, 7 B (copper, 80, bell-metal), those which are very ductile and malleable but soft and weak, as Nos. 26 to 29 (tin, 95 to 100) inclusive; and those which combine strength and ductility and possess, therefore, great resilience. as Nos. 2, 3 and 4 A (copper, 93 to 98, gun-metals). All intermediate qualities may be obtained, but these are typical and the most valuable of these compositions are evidently, for general purposes, those belonging to the last class, and of which the strain-diagrams lie between the extreme qualities, one set of which lie near the axis of abscissas, while the other set lie nearer the axis of ordinates. For some purposes, as when, for example, it is desirable to secure a high elastic limit as well as moderate toughness, alloys like ordnance bronzes, Nos. 4, 5, 6 (copper, 86 to 93), which are stiff and strong, although not very ductile, may be chosen. Cases may even arise, although certainly not often, in which the rigidity of bell-metal, No. 7 (copper, 80), may make that alloy valuable in consequence of its high elastic limit, notwithstanding its great deficiency in ductility.

The Tenacities of the valuable class of these metals range not far from 30,000 pounds per square inch (2,109 kilogs. per sq. cm.), the strength increasing somewhat with the proportion of tin up to 18 per cent. Within that range, the expression

$$T = 30{,}000 + 1{,}000\, t,$$

in which T is the tenacity and t the percentage of tin, may be taken to represent a maximum which selected materials

should always give. Hardness is here seen to increase steadily from pure copper to copper 75, at which point that of minimum ductility is reached. From this point it decreases steadily and with tolerable uniformity to the opposite end of the series.

Malleability takes an almost precisely opposite course, falling to zero at copper 60–65 and rising again to the end (pure tin).

Fusibility constantly lessens, as tin is added to copper, from end to end of the whole range.

The curve of ductility closely follows that of malleability in alloys rich in copper, but the lack of cohesion of tin causes a great falling off at the opposite end of the line.

CHAPTER XIV.

STRENGTH OF BRASSES AND OTHER COPPER-ZINC ALLOYS.

The Brasses include all the copper-zinc alloys containing one-half copper and upwards, and a few special alloys are also given the name, as are copper-tin-zinc alloys, of which the tin forms but a small proportion. The name bronze has been applied, occasionally, to these ternary alloys, also. The terms bronze and brass are used indifferently by the older writers, but the tendency to restrict each term to a binary alloy, or to a ternary alloy in which one constituent exists in very small proportion, is decidedly observable among later writers and they will be so used in this treatise.

In the cases of the brasses, as in that of the bronzes, no systematic investigation of the properties useful to the engineer had been made except by the U. S. Government. The U. S. Board, to which allusion has been already frequently made, authorized a determination of "the mechanical properties and of the physical and chemical relations of alloys of copper, tin, and zinc," under the arrangement of committees approved by the Board, which assigned to the Committee on Alloys the duty of "assuming charge of a series of experiments on the characteristics of alloys and an investigation of the laws of combination."

This research was conducted in the Mechanical Laboratory of the Department of Engineering of the Stevens Institute of Technology under the direction of the Author. The facts and data thus discovered and placed on record * will be summarized in this chapter after reference to earlier work on nearly related alloys.

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* Report of U. S. Board, Vol. II.; Ex. Doc. 23; 46th Congress, 2nd Session. Washington: Government Printing Office, 1881.

Earlier Experiments.—Mallet * found the tenacity of an alloy of copper, 90.7, zinc, 9.3, to be 27,000 pounds to the square inch (1,456 kilogs. per sq. cm.), with a specific gravity of 8.6; with 3 per cent. more zinc the strength was increased to very nearly 30,000 pounds (2,109 kilogs.). Copper, 85.4, zinc, 14.6, had a tenacity of about 32,000 pounds (2,249.6 kilogs.), and with copper, 83, zinc, 17, the figure became 31,000 (2,179 kilogs.). The tenacities varied little throughout the range and down to copper, 2, zinc, 1, which is a Muntz metal. Equal parts copper and zinc exhibited a tenacity of 20,000 pounds per square inch (1,406 kilogs. per sq. cm.) in Mallet's experiments; the Author has obtained, in some cases, 40,000 (2,812 kilogs.). Alloys rapidly become weaker, passing this maximum, as the proportion of zinc is increased, as will be seen later, passing, however, a second maximum at about copper, 10, zinc, 90, which gives figures one-third as great as the first maximum.

Brass cartridge metal tested with copper and steel by Lt. Metcalfe at the Bridesburg Arsenal in samples trimmed out to a contracted section of one inch (2.54 cm.), minimum breadth, and 0.03 inch (0.076 cm.) thick gave results as follows:

TENACITY AND ELONGATION OF CARTRIDGE METAL.

LOAD.		PURE COPPER.	COMMERCIAL COPPER.				BRASS.		OPEN HEARTH STEEL.	
Lbs.	Kilogs.						Unannealed.	Annealed.	I.	II.
500	227	0.024	0.005	0.005	.....	.....	.....	.....	.....	.....
600	272	0.040	0.020	0.015	.....	.....	.....	.....	.....	.....
800	363	0.078	0.063	0.040	0.033	00.27	.....	.....	.....	.....
1,000	454	0.155	0.150	0.087	0.050	0.057	0.013	0.050	0.0225	.....
1,100	499	.....	0.266	0.130	0.075	0.085	0.025	0.075	0.030	0.005
1,200	544	.....	.....	0.214	0.102	0.110	0.042	0.100	0.0425	0.0075
1,300	590	.....	.....	0.290	0.152	0.163	0.062	0.130	0.060	0.013
1,400	635	.....	.....	.....	0.266	0.270	0.085	0.165	0.0775	0.030
1,500	680	.....	.....	.....	.....	.....	0.117	0.220	0.140	0.065
1,600	726	.....	.....	.....	.....	.....	0.157	0.350	0.230	0.120
1,700	771	.....	.....	.....	.....	.....	0.217	.....	.....	.....
1,800	817	.....	.....	.....	.....	.....	0.322	.....	.....	.....

* *Phil. Mag.*, Vol. 21, 1842.

As the test-pieces were of the "grooved" form the elongations serve for comparison of these specimens, but have no absolute value.

Sterro-Metal, a brass which contains a little tin and iron, was tested by Baron de Rosthorn at Vienna, and gave the following results: *

TENACITY OF STERRO-METAL.

MATERIAL.	TENACITY.	
	Lbs. per sq. in.	Kilogs. per sq. cm.
Sterro-metal; cast	60,480	4,252
" " forged	76,160	5,354
" " cold-drawn	85,120	5,984
Gun-bronze; cast	40,320	2,834

This alloy contained copper, 55.04; zinc, 42.36; tin, 0.83; iron, 1.77.

The proportion of zinc may vary from 38 to 42 per cent. without appreciably altering the value of the alloy. The specific gravity of this metal was 8.37 to 8.40 when forged or wire drawn; it has great elasticity, stretching 0.0017 without set, and costs 30 to 40 per cent. less than gun-bronze. It has been forged into guns, cold from the casting. The strength of sterro-metal containing one per cent. and more of tin will be given in the following chapter on ternary alloys of copper, tin and zinc.

The Moduli of Elasticity, E., of various alloys have been found, as below, to the nearest round numbers:

* Holley; "Ordnance and Armor," p. 424.

MODULI OF ELASTICITY OF BRASSES.

METAL.	VALUE OF E.		AUTHORITY.	REMARKS.
	Lbs. on sq. in.	Kilogs. on sq. cm.		
Brass.....	9.000,000	632,700	Tredgold.	11 tin, 89 copper, cast.
"	12,000,000	843,600	Wertheim.	Rolled.
"	13,000,000	913,900	Bauschinger.	Rolled.

As will be seen, presently, the value is very variable with ordinary cast alloys of copper and zinc, but should be tolerably uniform with rolled and drawn materials.

Copper-Zinc Alloys, including the brasses, were studied by the Author, and the investigation was, as already stated, conducted in a similar manner to that described in the discussion of the alloys of copper and tin.*

The specimens were in the form of bars, and were cast in an iron mould square in section, and similar in dimensions to that used in making bronzes. The experiments were made upon these bars as cast under ordinary conditions as before. The effects of different methods of casting, of slow and rapid cooling, of compression, either of the fluid metal or after solidification, and of rolling, tempering and annealing, were to have been made the subject of a special research.

Two series of these alloys were made and tested. The first series was composed of bars differing in composition by 5 per cent. The bars of the second series also differed in composition by 5 per cent., the first bar containing 2½ per cent. zinc, the last bar containing 97½ per cent.

The bars were first tested by transverse stress; the two pieces remaining after each transverse test were turned to size and tested by tension, and the four pieces thus formed

* This account is mainly abridged from the Report to the Committee on Alloys of the U. S. Board.

were tested by torsion. Some tests were made by compression. The turnings from the tension test-pieces were analyzed. The specific gravities were also determined.

The total weight of each casting was 4.5 kilograms (9.92 pounds).

Compositions Tested.—A following table (p. 461) gives the compositions of the bars according to the original mixtures, the compositions of two portions of each bar as subsequently determined by analysis, and the specific gravities.

Bar No. 16 was made by melting together the upper half of bar No. 17 (21.00 copper, 77.59 zinc) and the lower half of bar No. 15 (25.98 copper, 72.90 zinc).

The mould was heated each time before pouring into it the molten metal, the temperature given to it being higher the larger the amount of copper in the alloy. In melting the metal for bars, No. 7 to No. 21 (35 per cent. zinc to pure zinc), inclusive, except No. 16, the copper was melted first and covered with a layer of charcoal. The zinc was melted in a separate crucible, and poured into the crucible containing the molten copper, through the layer of charcoal. The mixture was thoroughly stirred with a dry stick. Some volatilization of the zinc took place, the amount being greater at some times than at others; but the causes of this variation were not determined.

Bars No. 1 to No. 6 (5 to 30 per cent. zinc) were made by first melting the copper, and then adding the zinc in the solid state. The losses of zinc vary very irregularly, and in two cases, bars Nos. 18 and 20 (85 and 95 per cent. zinc), there appeared to have been a greater loss of copper than of zinc.

The temperature of casting was then found by the formula

$$x = \frac{P'(t' - t)}{Pc} + t',$$

in which P' is the weight of the water, P the weight of metal poured, t the temperature of the water before, and t' after.

ALLOYS OF COPPER AND ZINC.

Summary of Average Results of Experiments.

NUMBER.	COMPOSITION BY ORIGINAL MIXTURE.		MEAN COMPOSITION BY ANALYSIS.		MEAN SPECIFIC GRAVITY.	TESTS BY TRANSVERSE STRESS.					TESTS BY TENSILE STRESS.					COMPRESSION TESTS.		TESTS BY TORSIONAL STRESS.					
											Tensile strength per square inch of—							Torsional moment.		Ductility.			
	Cu	Zn	Cu	Zn		Modulus of rupture.	Elastic limit (per cent. of breaking load).	Total deflection before breaking (inches).	Resilience within a deflection of ¼ inches (foot-pounds).	Modulus of elasticity.	Original section (pounds).	Fractured section (pounds).	Elastic limit (per cent. of breaking load).	Total elongation (per cent.).	Diameter of fractured section (per cent. of original section).	Crushing strength per square inch (pounds).	Amount of compression (per cent.).	Maximum (foot-pounds).	At elastic limit (per cent. of maximum).	Angle of torsion (degrees).	Extension of exterior fibre.	Resilience (foot-pounds).	Modulus of elasticity.
0*	Cast copper		.....	.....	8.791	29,848	14.0	Bent.	191.25	.....	27,800	32,496	51.8	6.47	92	42,000	10+	143.24	35.3	153.0	0.3084	320.35	..
22†	97.5	2.50	97.83	1.88	8.791	.....	.....	.....	.....	.....	27,240	39,570	.....	.....	83	.....	.....	130.01	30.2	357.0	1.1889	643.21	..
1†	95.0	5.0	96.07	3.79	8.825	.....	34.1	.....	.....	.....	.....	.....	.....	.....	..	29,000	10+	97.25	24.8	174.0	0.3786	211.79	..
23†	92.5	7.5	92.32	7.68	8.746	21,734	30.0	Bent.	144.49	13,842,723	.....	.....	.....	.....	..	.....	.....	87.17	39.3	137.0	0.2483	143.25	..
2†	90.0	10.0	90.56	9.42	8.773	.....	57.9	.....	.....	.....	.....	.....	.....	.....	..	30,000	10+	140.09	17.2	458.0	1.6907	896.69	..
24†	87.5	12.5	88.94	10.97	8.747	.....	.....	.....	.....	.....	.....	.....	.....	.....	..	.....	.....	114.89	16.6	230.0	0.6043	333.91	..
3†	85.0	15.0	83.80	10.06	8.656	.....	53.3	.....	.....	.....	.....	.....	.....	.....	..	29,500	10+	104.81	27.9	607.0	2.5011	881.59	..
25	82.5	17.5	82.93	16.98	8.633	23,197	41.2	Bent.	164.32	14,425,146	32,600	57,086	26.1	26.7	76	.....	.....	155.37	28.7	328.8	1.0532	691.06	..
4	80.0	20.0	81.91	17.99	8.598	21,193	45.2	Bent.	140.93	12,469,814	32,670	57,749	30.6	31.4	75	.....	.....	165.93	27.5	344.8	1.1318	776.79	..
26	77.5	22.5	77.39	22.45	8.574	25,374	44.4	Bent.	152.99	14,734,473	35,630	68,353	20.0	35.5	72	.....	.....	169.37	30.9	311.5	0.9748	703.62	..
5	75.0	25.0	76.65	23.08	8.528	22,325	50.0	Bent.	152.11	13,407,355	30,520	50,921	24.6	35.8	79	42,000	10+	165.55	26.0	266.5	0.7669	563.19	..
27	72.5	27.5	73.20	26.47	8.465	25,894	43.2	Bent.	189.64	14,509,957	31,580	58,641	23.7	38.5	74	.....	.....	168.66	28.3	292.7	0.8866	629.51	..
6	70.0	30.0	71.20	28.54	8.444	24,468	51.4	Bent.	161.42	14,035,326	30,510	48,956	29.5	29.2	79	.....	.....	163.62	24.0	268.7	0.7780	563.39	..
28	67.5	32.5	69.74	30.06	8.384	26,930	46.1	Bent.	196.87	12,565,749	28,120	38,773	28.7	20.7	85	.....	.....	143.45	23.9	202.3	0.4912	357.71	..
7	65.0	35.0	66.27	33.50	8.371	28,459	53.7	Bent.	226.98	13,831,256	34,800	65,744	25.1	37.7	75	.....	.....	176.64	29.4	256.8	0.7279	605.65	..
29	62.5	37.5	63.44	36.36	8.411	43,210	53.3	Bent.	271.28	14,101,299	48,300	69,876	32.8	31.7	83	.....	.....	202.17	27.0	229.8	0.6061	632.54	..
8	60.0	40.0	60.94	38.65	8.405	38,968	56.1	Bent.	211.79	12,231,927	41,065	57,365	40.1	20.67	84	75,700	10+	193.65	29.4	201.8	0.4897	527.28	..

* Bar No. 30, Report of Alloys of Copper and Tin. † Defective bar.

NUMBER.	COMPOSITION BY ORIGINAL MIXTURE.		MEAN COMPOSITION BY ANALYSIS.		MEAN SPECIFIC GRAVITY.	TESTS BY TRANSVERSE STRESS.				TESTS BY TENSILE STRESS.				COMPRESSION TESTS.		TESTS BY TORSIONAL STRESS.				
	Cu	Zn	Cu	Zn		Modulus of rupture.	Elastic limit (per cent. of breaking load).	Total deflection before breaking (inches).	Resilience within a deflection of $\frac{1}{10}$ inches (foot-pounds).	Modulus of elasticity.	Tensile strength per square inch of—		Elastic limit (per cent. of breaking load).	Total elongation (per cent.).	Diameter of fractured section (per cent. of original section).	Crushing strength per square inch (pounds).	Amount of compression (per cent.).	Torsional moment.	Ductility.		Resilience (foot-pounds).	Modulus of elasticity.
											Original section (pounds).	Fractured section (pounds).						Maximum (foot-pounds).	At elastic limit (per cent. of maximum).	Angle of torsion (degrees).	Extension of exterior fibre.		
30	57.5	42.5	58.49	41.10	8.363	63,324	47.5	Bent.	384.43	11,890,008	50,450	60,785	51.4	10.09	99	.....	.....	227.04	30.6	92.5	0.1210	274.40	...
9	55.0	45.0	55.15	44.44	8.233	42,463	37.5	Bent.	198.78	9,538,189	44,286	57,774	44.0	15.31	89	78,000	10+	208.77	32.7	109.0	0.1948	308.18	...
31	52.5	47.5	54.86	44.78	8.301	47,955	38.8	Bent.	283.45	10,816,045	46,400	53,756	53.9	7.97	92	.....	.....	253.26	34.4	71.5	0.0735	197.86	...
10	50.0	50.0	49.66	50.14	8.291	33,467	34.0	1.357	68.83	11,574,491	30,990	34,636	54.5	4.67	96	117,400	10+	172.23	36.0	37.8	0.0310	98.15	...
32	47.5	52.5	48.99	50.82	8.216	40,189	43.6	0.6140	29.69	12,700,126	26,950	37,259	100.0	0.84	93	.....	.....	175.64	36.5	15.5	0.0036	30.99	...
11	45.0	55.0	47.56	52.28	....	48,471	33.1	1.1693	91.63	14,027,268	24,150	84,549	100.0	0.79	99	121,000	10+	154.59	38.5	13.1	0.0026	23.56	...
33	42.5	57.5	43.36	56.22	8.084	17,691	100.0	0.0982	2.89	12,918,211	9,170	9,179	100.0	.....	..	.....	.....	88.23	100.0	2.3	0.00017	5.75	...
12	40.0	60.0	41.30	58.12	8.061	7,761	100.0	0.0357	0.32	16,367,068	3,727	3,727	100.0	.....	..	.....	.....	18.31	100.0	1.8	0.0001	0.86	...
34	37.5	62.5	38.36	61.05	7.982	6,727	100.0	0.0430	0.36	10,219,336	3,087	3,087	100.0	.....	..	.....	.....	10.34	100.0	0.75	0.0002	0.39	...
13	35.0	65.0	36.62	63.78	7.974	4,893	100.0	0.0245	0.15	14,121,779	2,656	2,656	100.0	.....	..	.....	.....	9.67	100.0	1.4	0.0006	0.48	...
35	32.5	67.5	35.68	63.71	7.966	8,895	100.0	0.0404	0.87	.....	2,397	2,397	100.0	.....	..	.....	.....	16.46	100.0	0.75	0.0011	0.68	...
14	30.0	70.0	32.94	66.23	7.811	8,296	100.0	0.0355	0.37	17,615,945	1,774	1,774	100.0	.....	..	.....	.....	28.86	100.0	1.2	0.0005	0.70	...
36	27.5	72.5	29.20	70.17	7.766	16,579	100.0	0.0449	1.32	14,748,167	6,414	6,414	100.0	.....	..	.....	.....	39.80	100.0	1.5	0.0009	0.93	...
15	25.0	75.0	25.77	73.45	7.675	22,893	100.0	0.1136	3.75	16,182,099	9,680	9,680	100.0	0.35	100.0	110,822	5.85	65.98	100.0	1.0	0.0002	0.56	...
16	22.5	77.5	23.92	73.00	7.687	23,850	100.0	0.1331	4.53	14,384,245	7,931	7,931	100.0	.....	.....	.....	.....	74.64	100.0	1.5	0.0005	1.16	...
37	20.0	80.0	20.81	77.63	7.418	22,972	100.0	0.1259	3.67	14,469,651	9,000	9,000	100.0	0.16	100.0	52,152	2.75	65.35	100.0	0.8	0.0002	0.18	...
17	17.5	82.5	17.49	81.62	7.225	14,000	100.0	0.0922	1.68	11,659,140	5,350	5,350	100.0	0.14	100.0	.....	.....	25.97	100.0	1.0	0.0003	0.24	...
38	15.0	85.0	14.19	85.10	7.163	20,744	100.0	0.1840	6.52	14,180,866	8,500	8,500	100.0	0.31	100.0	48,892	10.8	49.46	100.0	1.4	0.0004	0.42	...
39	12.5	87.5	12.12	86.67	7.238	35,026	64.0	0.3124	12.49	11,350,433	19,413	12,413	100.0	0.36	100.0	.....	.....	82.16	100.0	2.5	0.0009	2.30	...
19	10.0	90.0	10.30	88.88	7.251	41,347	73.0	0.5456	44.66	12,809,469	14,450	14,450	100.0	0.39	100.0	49,000	10+	89.81	85.6	7.1	0.0100	9.36	...
40	7.5	92.5	7.29	92.07	7.131	37,547	37.7	0.7910	49.37	11,757,262	10,650	10,650	100.0	0.38	100.0	.....	10+	137.01	67.3	21.9	0.0840	54.97	...
23	5.0	95.0	4.35	94.59	7.108	26,162	50.7	0.4012	21.73	9,868,876	18,265	18,265	100.0	0.40	100.0	4,800	10+	87.11	48.8	41.3	0.0470	35.66	...
41	2.5	97.5	2.45	96.43	7.080	23,137	31.8	0.4097	17.15	10,844,766	11,425	11,425	87.8	0.83	99.9	24,000	10+	36.66	38.1	141.3	0.2630	37.79	...
21	Cast zinc.		.....	.....	7.143	7,539	57.1	0.1244	1.49	6,964,044	3,400	5,433	73.0	0.09	99.7	.....	.....	.....	.....	.....	.....	.....	...

Conclusions from Tests.—In the preceding table, the "breaking load" by transverse stress is that which either causes a deflection of 3½ inches (9 cm.), or breaks the bar within that limit. The limit of elasticity is not a definitely marked point in any cases in which brasses or bronzes are under test, and the quantity here given as a limit is to be taken as approximate only, and not as representing a fixed natural quantity. The moduli of elasticity were calculated from a series of deflections and loads, and the highest of the series of values so obtained is usually recorded as probably most correct, errors of observation and accidental errors usually operating to depress the value.

Alloys containing less than 10 per cent. zinc were usually somewhat defective and spongy. Fluxing may be expected to give sound casting only when special care is taken, as copper has a great affinity for oxygen and absorbs air freely when the metal is fluid.

Alloys containing less than 55 per cent. zinc are yellow, and have been classed as "useful alloys." Those containing less than 40 per cent. are noticeably weaker than those containing from 40 to 55. The former are ductile and have either a fibrous or an earthy fracture; the latter are, in some cases, of nearly or quite double their strength, with less ductility, and the fractures are granular and lustrous. The maximum strength is found not far from the composition, copper, 60; zinc, 40. The white alloys (zinc, 40 to 50; copper, 60 to 50) are weak, brittle, vitreous, and useless for ordinary purposes of construction. The blue-gray alloys (zinc, 70 to 100) are granular or crystalline, stronger than the white, but weaker than the yellow alloys, and have considerable ductility. The range of valuable composition, which, in the copper-tin alloys or bronzes, extends over a variation of but 25 per cent., covers a range of 50 per cent. in the list of brasses. In both classes, a sudden and great variation of properties is observed at a certain point, and the maximum and minimum are not far apart in either the brasses or the bronzes.

CHAPTER XV.

STRENGTH OF KALCHOIDS AND OTHER COPPER-TIN-ZINC ALLOYS.

The Kalchoids.—The bronzes and brasses were not distinguished by early Greek and Latin writers, who applied the same names to both (Greek, *Kalchos;* Latin, *Aes.*). It has also been common to add to the copper-tin, or bronze, alloys small proportions of zinc, and lately, to the copper-zinc alloys, or brasses, small quantities of tin, thus forming an intermediate collection of indefinite number and proportions, to which may be here applied the indefinite terms of the ancients, and which may be called the kalchoids, or kalchoid alloys. These and solders and other copper-tin-zinc alloys naturally fall into one group.

The effect of substituting a small quantity of zinc for tin in making the bronzes is not perceivable except as making them a little less subject to "cold shuts," or blow-holes and similar defects, making them a little softer and a trifle weaker and giving them slightly better working qualities when turned in the lathe or otherwise shaped with cutting tools. The effect of substituting a small proportion of tin for zinc in the brasses, however, is very marked, causing increased hardness, strength, rigidity and elasticity, and, if the proportions of copper and zinc are about equal, making the alloy too hard and brittle to work.

In general, the effects of the two metals, zinc and tin, upon copper are similar, but that of adding tin is much more observable than that of introducing zinc. It was found in collating the results of investigations made by the Author for the U. S. Board and in other researches, that the effect of one part tin is nearly equivalent to two parts of zinc.

These facts are well illustrated in the account of that work

to be presented in the present chapter. They are well shown also, in experiments on "sterro-metal."

Sterro-metal, tested at Woolwich, exhibited a tenacity somewhat variable with composition, but always considerable, as seen below.* Its stiffness and resistance to abrasion were also found to be very great. The tenacity may be taken at an average of 60,000 pounds per square inch (4,218 kilogs. per sq. cm.), its elastic limit at one-half that amount, and its elongation at 0.07. The test pieces used were three diameters long.

TENACITY OF STERRO-METAL.

Breaking weight, lbs. per square inch.	Kilogs. per square cm.	Ultimate elongation at breaking point in inches.	Treatment.	Mixture.
60,020	4,213	.1	as received.	Austrian.
46,060	3,386	.05	cast in sand.	Copper, 60; zinc, 39; iron, 3; tin, 1.5.
43,120	3,032	.015		
54,220	3,819	.016	cast in iron.	Copper, 60; zinc, 44; iron, 4; tin, 2.
52,080	3,662	.02	cast in iron and annealed.	
62,720	4,410	.045	forged red hot.	
70,806	4,978	....	cast in iron and	.....
72,845	5,121	....	forged red hot.	.....
76,160	5,355	....	.....	Copper, 60; zinc, 37; iron, 2; tin, 1.
84,920	5,985	....	.....	Copper, 60; zinc, 35; iron, 3; tin, 2.
60,480	4,252	....	after simple fusion.	Copper, 55.04; spelter, 42.36; iron, 1.77; tin .83.
76,160	5,355	....	forged red hot.	
84,920	5,985	....	drawn cold.	
62,720	4,410	....	after simple fusion.	
73,680	5,040	....	forged red hot.	Copper, 57.63; spelter, 40.22; iron, 1.86; tin, 0.15.
82,880	5,827	....	drawn cold and reduced from 100 to 77 transverse sectional area.	

* "Strength of Materials;" Anderson, Lond., 1872.

This greater tenacity, as compared with brass and Muntz metal, is probably partly due to the presence of iron, but largely also to the one or two per cent. tin. As will be seen later, the Author has obtained higher figures by the use of tin alone.

The Copper-Tin Zinc Alloys were made the subject of a special and systematic investigation, at the request of the Committee on Alloys of the U. S. Board of 1875, with a view to the determination, not simply of the strength and other properties of specific combinations, but to ascertain the law governing the variation of such useful qualities with variation of composition, in such manner that, by the study of a limited number of these alloys, the properties of all possible combinations of the three metals might be fully determined. Before entering upon this investigation it, therefore, became necessary to devise a plan and to invent a method of research, which should enable the Author so to choose the set of alloys to be studied as to make their number a minimum, while so fixing their proportions as to distribute them with a satisfactory degree of uniformity over the whole field to be explored, thus making the research complete and productive of a maximum result at minimum cost of time, labor, and money.

The Plan of Investigation, if it could be made thus effective, should evidently lead not only to the determination of the strength and elasticity, ductility and resilience, and other important properties of all possible alloys of copper with zinc, copper with tin, and tin with zinc, and of all copper-tin-zinc alloys, but should also reveal the composition of the alloy of maximum strength or other quality, or combination of qualities, that could possibly be formed and that man can make, using these elements. Such a plan was devised by the Author. Its principle is as follows:*

In any equilateral triangle, *B*, *C*, *D*, Fig. 78, let fall perpendiculars from the vertices to the opposite sides, as for

* On a New Method of Planning Researches, etc., by R. H. Thurston. Proc. Assoc. for Advancement of Science, vol. xxvi. Trans. Am. Soc. C. E. 1881, No. 214.

example, $\overline{CE}$. From any point within the triangle, A, let fall perpendiculars $\overline{AG}$, $\overline{AH}$, $\overline{AF}$, and draw $\overline{AB}$, $\overline{AC}$, $\overline{AD}$ to the vertices, thus obtaining three triangles, $\overline{ABD}$, $\overline{ABC}$, $\overline{ACD}$; their sum is equal to the area of the whole figure $\overline{BCD}$.

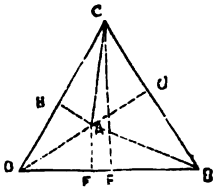


FIG. 78.

Now we have, since the triangle is equilateral, and

$$\frac{\overline{CE} \times \overline{BD}}{2} = \frac{\overline{AF} \times \overline{BD}}{2} + \frac{\overline{AG} \times \overline{BC}}{2} + \frac{\overline{AH} \times \overline{CD}}{2},$$

$$\overline{CE} \times \overline{BD} = (\overline{AF} + \overline{AG} + \overline{AH}) \times BD;$$

and

$$\overline{CE} = \overline{AF} + \overline{AG} + \overline{AH};$$

which follows wherever the point A may be situated; it is true for every point in the whole area $\overline{BCD}$. Assuming the vertical $\overline{CE}$ to be divided into 100 parts; then $\overline{AF} + \overline{AH} + \overline{AG} = 100$ and $\frac{\overline{AF}}{100}$, $\frac{\overline{AH}}{100}$, $\frac{\overline{AG}}{100}$, measures the relation of each of the altitudes of the small triangles to that of the large one.

But we may now conceive the large triangle to represent a triple alloy of which the areas of the small triangles shall each measure the proportion in which one of the constituents enters the compound, and

$$BCD = 100 \text{ per cent.} = (\overline{AF} + \overline{AG} + \overline{AH})\, BD, \text{ or}$$

$CE = 100$ per cent. $= \overline{AF} + \overline{AG} + \overline{AH}$ per cent. and the altitude of each small triangle measures the percentage of some one of the three elements which enter that alloy which is identified by the point. Thus every possible alloy is represented by some one point in the triangle $\overline{BCD}$, and

every point represents and identifies a single alloy, and only that. The vertices *B*, *C*, *D*, in the case to be here considered, represent respectively, copper = 100, tin = 100, zinc = 100.

Alloys Chosen for Test.—Thus, having determined a method of studying all possible combinations, the Author next prepared to examine this field of work in the most efficient and complete manner possible, with a view to determining, by the study of a limited number of all possible copper-tin-zinc alloys, the properties of all the numberless, the infinite, combinations that might be made, and with the hope of detecting some law of variation of their valuable qualities with variation of composition, and thus ascertaining which were the most valuable for practical purposes.

With this object in view, the triangle laid down to represent this research, was laid off in concentric triangles, Fig. 79, varying in altitude by an equal amount—10 per cent.—on which were laid out the proposed series of alloys:

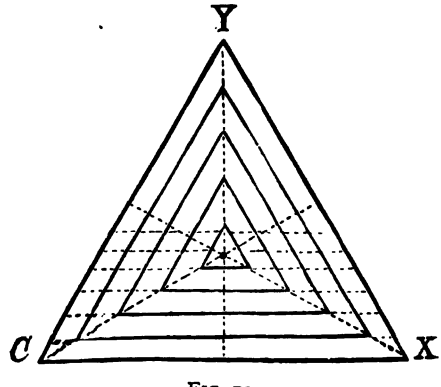
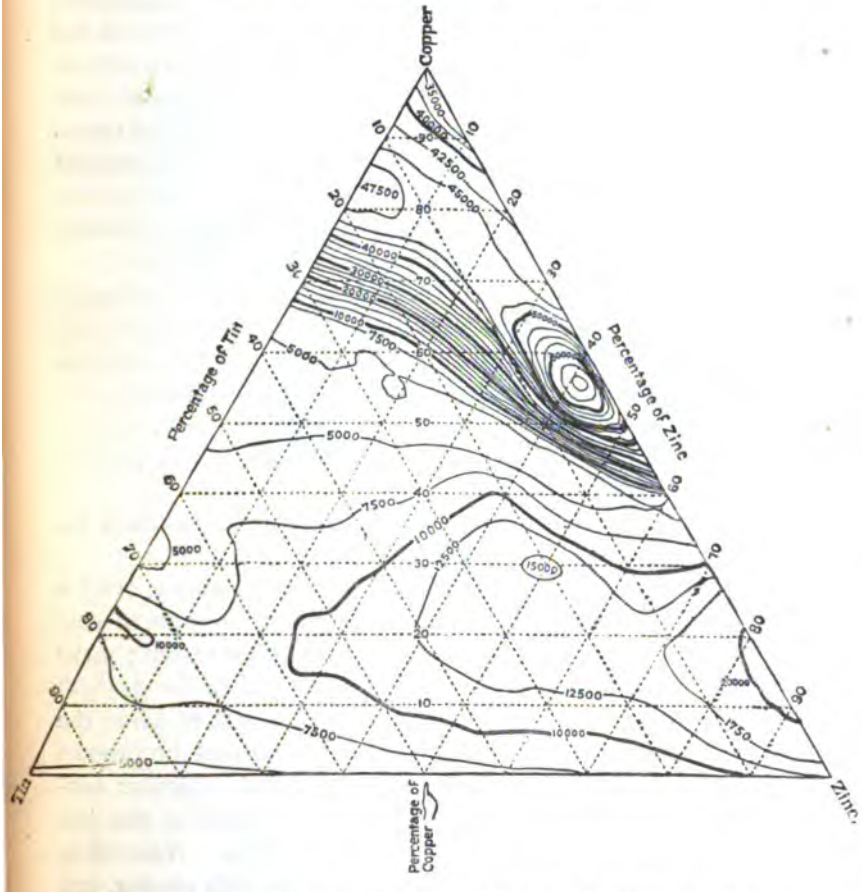


FIG. 79.

The Method of Exhibiting and Recording Results, which, as devised by the Author for this case, was intended so to present the data secured in the manner described that it could be seen, at a glance, what law, if any, controlled the

FIG 80.—COPPER-TIN-ZINC ALLOYS.



variation of strength, or of the quality, with change of composition, and that the investigator could readily determine where to seek the alloy possessing a maximum of any quality, desirable or otherwise, should it happen, as would in all probability be the case, that that alloy had not been included

among those studied during the investigation. The plan finally adopted was novel but as thoroughly satisfactory as was that of laying out the work. It was the following:

The figures obtained by the test of alloys studied were inserted upon a triangular plan, each in its place as determined, in the manner described already, for that composition.

When the figures thus obtained had been entered on the triangular map, lines of equal strength, of equal ductility, or of equal resistance could be drawn, as in topographical work lines of equal altitude are drawn, and the map became thus a useful representation of the valuable qualities of all possible alloys.

Figure 80 represents such a map* of all copper-tin-zinc alloys. The scale of altitudes is obtained by considering the relation of tension to torsion resistance as 25,000 pounds per square inch (1,758 kilogrammes per square centimetre) for each 100 foot-pounds (13.82 kilogrammetres) of torsional moment for the standard test-specimen, which specimen was turned to a standard gauge, and made ⅝ inch (1.84 cm.) diameter and 1 inch (2.54 cm.) long in the cylindrical part exposed to strain.

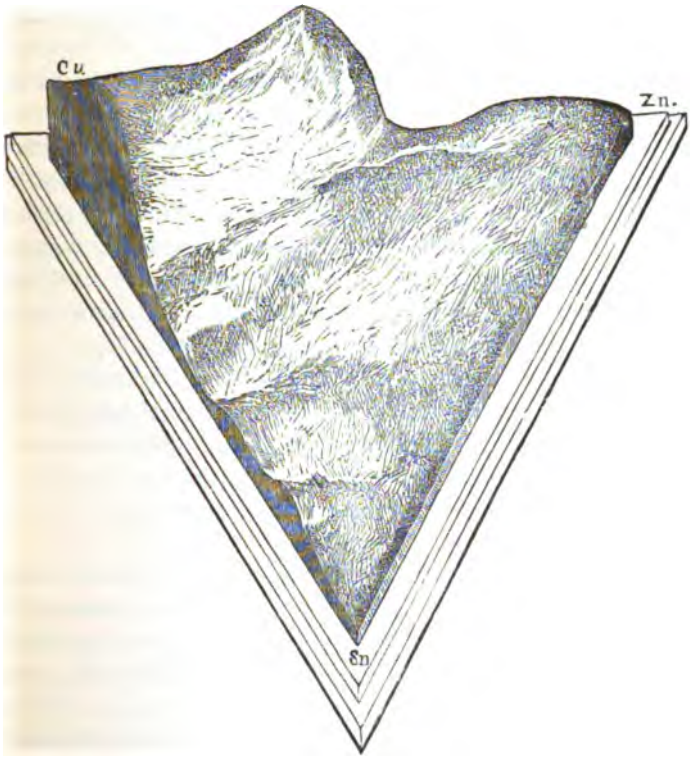
These facts were also exhibited by another method devised by the Author; thus:

Upon a triangular metal base, laid off as above, erect a light metallic staff by drilling a hole for its support at each point laid down as representative of an alloy tested; make the altitude of each of these wires proportional to the strength of that alloy. There is thus produced a forest of wires, the tops of which are at elevations above the base-plane proportional to the strengths of the alloys studied. Similar constructions may be made to represent the elasticity, the ductility, or any other property of all these alloys. Next fill in between these verticals with clay, or better, with plaster, and carefully mould it until the tops of all the wires are just visible, shining points in the now smooth surface of the model.

* Reports of U. S. Board testing Iron, Steel, etc. Washington, 1878–1881. The Strongest of the Bronzes; R. H. Thurston. Trans. Am. Soc. C. E. 1881, no. ccxlv.

The surface thus formed will have a topography characteristic of the alloys examined, and its undulations will represent the characteristic variations of quality with changing proportions of the three constituents. This was made for the Author,

FIG. 81.—MODEL OF COPPER-TIN-ZINC ALLOYS.



and was cast in an alloy of maximum tenacity, the plaster cast made as above being used as a pattern.

Figure 81 is a representation of this model made from a photograph.

General Deductions.—The remarkable variations of quality here so strikingly shown attracted attention, and a further investigation was made.

These alloys were purposely made without other precau-

tions than those observed by every founder, and without using deoxidizing fluxes.

The data obtained were consequently quite variable, and the result of this work indicated that the same alloy, especially where the proportion of copper is great, may give very different figures accordingly as it is more or less affected by the many conditions that influence the value of all brass-foundry products.

Some variations in the model are probably due to such accidental circumstances. But, allowing for minor variations, it is evident that the alloys of maximum strength are grouped, as shown in Figures 80 and 81, about a point not far from copper = 55, zinc = 43, tin = 2. This point is encircled in the map, Figure 80, by the line marked 65,000 pounds per square inch (4,570 kilogs. per sq. cm.) tenacity, and represented on the model, Figure 81, by the peak of the mountain seen at the farthest side—the copper-zinc side.

This is the strongest of all bronzes, and an alloy of this composition, if exactly proportioned, well melted, perfectly fluxed, and so poured as to produce sound and pure metallic alloy, with such prompt cooling as shall prevent liquation, is the strongest bronze that the engineer can make of these metals.

The Author finally made this alloy, and of it constructed the model represented in the last figure. It is a close-grained alloy of rich color, fine surface, and takes a good polish. It oxidizes with difficulty, and the surface then takes on a pleasant shade of statuary bronze green.

The *exact* composition of this, which the Author has called the "maximum alloy," was not considered as fully determined by this preliminary investigation. The metals used in making it were commercial copper, tin, and zinc, and the methods of mixing, melting, and casting were purposely those usual in the ordinary brass foundry, and necessarily subject to some uncertainty of result.

The precise location of this "strongest of the bronzes" was intended to be made in an independent and later research, in which chemically pure metals, more carefully handled, and

especially well fluxed with phosphorus or other effective flux, should be used. This research was carried out several years later, under the eye of the Author, and an account of it is given later.

Testing the alloy above referred to, it was found to have considerable hardness and but moderate ductility, though tough and ductile enough for most purposes; it would forge if handled skilfully and carefully, and not too long or too highly heated, had immense strength, and seemed unusually well adapted for general use as a working quality of bronze. In composition it is a brass, with a small dose of tin.

The alloy made as representing the best for purposes demanding toughness, as well as strength, contains less tin than the above composition (Cu, 55; Sn, 5; Zn, 44.5).

It had a tenacity of 68,900 pounds per square inch (4,841 kilogs. per sq. cm.) of original section, and 92,136 pounds (6,477 kilogs.) on fractured area, and elongated 47 to 51 per cent. with a reduction to from 0.69 to 0.73 of its original diameter.

No exaltation of the normal elastic limits was observable during tests made for the purpose of measuring it if noted. This alloy was very homogeneous, two tests by tension giving exactly the same figure, 68,900. The fractured surface was in color pinkish yellow, and was dotted with minute crystals of alloy produced by cooling too slowly. The shavings produced by the turning tool were curled closely, like those of good iron, and were tough and strong.

The Strain-Diagrams from the autographic machine (No. 1,001) are shown in *fac simile* in the accompanying engraving. The tenacity, as estimated from the resistance to torsion, is nearly equal to that determined by direct experiment, and four samples tested give strain-diagrams that are all nearly precisely alike. They exhibit an ill-defined elastic limit, *e*, at about $\frac{2}{3}$ their ultimate resistance, and about the same as a piece of excellent gun-bronze (Cu, 90; Sn, 10 per cent.), 1,252 *A*, the strain-diagram of which lies beside them in dotted line. The elastic resistance, which is measured by the area of the curve up to *e*, is superior to that of the gun-bronze, and the elastic range is seen to be greater, on

inspection of the "elasticity lines," e' e'. In ductility they excel 1,252 *A*, somewhat, as is seen by comparing 1,001 *A* with 1,252 *A*. Their toughness is shown by the great area and the altitude of the curve; their excellence of quality is also shown by its smoothness of outline. The homogeneousness of structure is exhibited by the similarity of the diagrams and by the smoothness of the bend at *e*, which marks the elastic limit.

At *f* is a depression of the normal line of elastic limits produced by 17 hours intermission of distortion under the load there carried. This slight depression marks this alloy as one of the "tin class."

Diagram 1,252 *B* is given by a fine gun-bronze; 1,001 *x* is an hypothetical diagram, such as would be produced were the alloy here described so carefully fluxed and cast as to exceed in strength the unfluxed alloys actually tested, 1,001 *A*, *B*, *C*, *D*, in as great a proportion as 1,252 *B* excels 1,252 *A*. The diagram 1,001 *y* would be produced were it possible to so far improve this alloy as to cause it to excel 1,252 *A* as greatly as No. 1,001 actually did excel the gun-bronze made under similar conditions in this preliminary rough work. No. 1,004 *A* is copied to exhibit the superiority of the alloy 1,001 to one but little removed from it, and which is considered by some brass founders an excellent composition.

The Tenacities of the Strong Alloys of copper, tin, and zinc, as obtained by the investigation just described, are, as has been seen, quite variable, and the result of the whole has been fully confirmatory of Major Wade's conclusion relative to useful alloys of copper with softer metals: that they are subject to great variation of quality, as ordinarily made, and that it is impossible to predict with certainty the soundness, the uniformity, and homogeneousness, or the strength of any casting in bronze or brass. A study of the figures here obtained, however, and of the map or model exhibiting them, shows that, with good castings of any of the more valuable compositions, certain methods of variation and a general law may be formulated. Thus, for true bronzes containing usual amounts of tin, the tenacity, as such castings are commonly

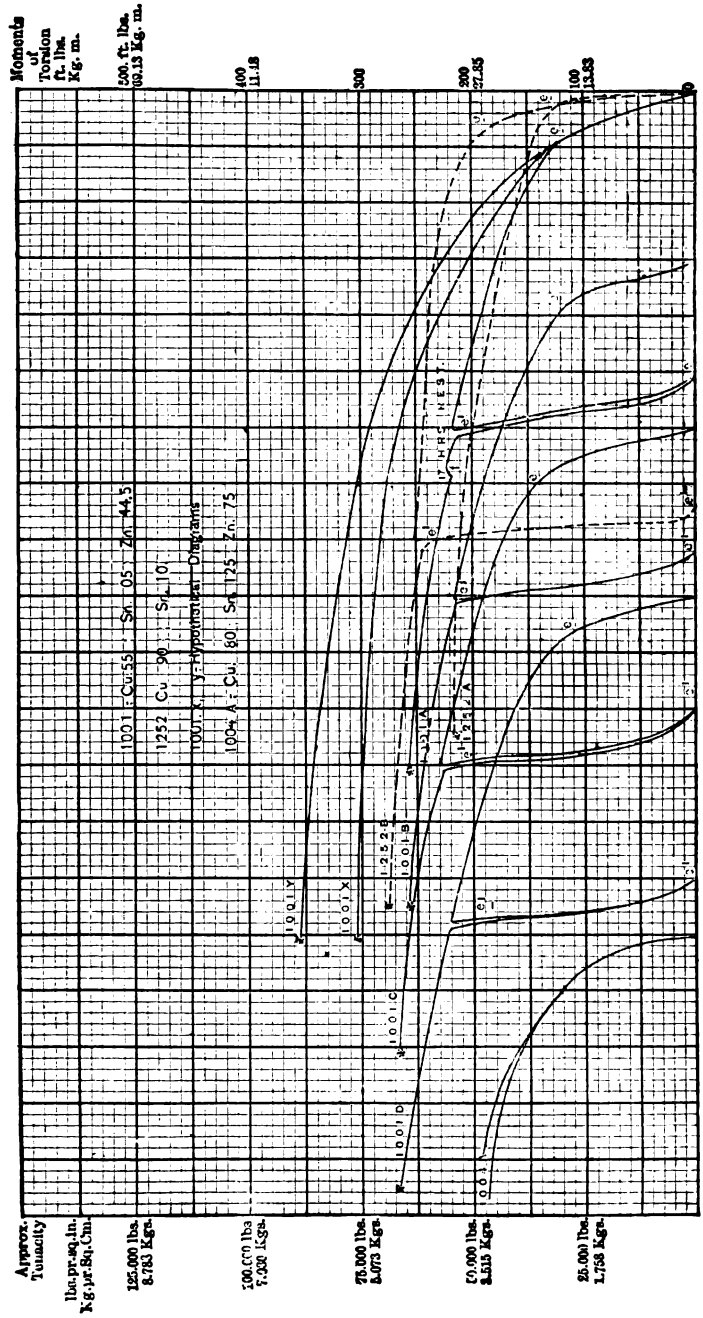


FIG. 82.—STRAIN-DIAGRAMS OF BRONZES.

made in the course of every-day business in the foundry, should be about—

$$T_c = 30{,}000 + 1{,}000\, t;$$

where t is the percentage of tin, and not above 15 per cent. Thus gun-bronze can be given about 30,000 + (1,000 × 10) = 40,000 pounds per square inch, if well made. In metric measures

$$T_c^1 = 2{,}109 + 70.3\, t,$$

giving for good gun-metal 2,109 × 703 = 2,812 kilogs. per sq. cm.

For brass (copper and zinc) the tenacity may be taken as

$$T_z = 30{,}000 + 500\, z;$$

where the zinc is not above 50 per cent.; and

$$T_z^1 = 2{,}109 + 35.15\, z.$$

Thus copper 70, zinc 30, should have a strength of 30,000 + (500 × 30) = 45,000 pounds per square inch, or 2,109 + (35.15 × 30) = 3,165 kilogrammes per square centimetre.

Referring once more to Figures 80 and 81, it is seen that a line of maximum elevation crosses the field marking the crest of the mountain in Fig. 81, of which the "maximum bronze" is the peak. This line of valuable alloys may be practically covered by the formula:

$$M = z + 3\, t = \text{Constant} = 55,$$

in which z is the percentage of zinc, and t that of tin. Thus a maximum is found at about $t = 0$, $z = 55$, while the other end of the line is $z = 0$, $t = 18$.

Along this line the strength of any alloy should be at least

$$T_m = 40{,}000 + 500\,z.$$

$$T_m^1 = 2{,}812 + 35.15\,z.$$

Thus the alloy $z = 1$, $t = 18$ will also contain copper $= 100 - 19 = 81$, and this alloy Cu, 81; Zn, 1; Sn, 18, should have a tenacity of at least

$$T_m = 40{,}000 + (500 \times 1) = 40{,}500 \text{ lbs. per sq. in.}$$

$$T^1_m = 2{,}812 + (35.15 \times 1) = 2{,}847 \text{ kilogs. per sq. cm.}$$

The alloy Cu, 60; Zn, 5; Sn, 16, should have at least the strength

$$T_m = 40{,}000 + (500 \times 5) = 42{,}500 \text{ lbs. per sq. in.}$$

$$T^1_m = 2{,}812 + (35.15 \times 5) = 2{,}988 \text{ kilogs. per sq. cm.}$$

while the alloy Zn, 50; Sn, 2; Cu, 48, should give, as a minimum per specification:

$$T_m = 40{,}000 + (500 \times 50) = 65{,}000 \text{ lbs. per sq. in.}$$

$$T^1_m = 2{,}812 + (35.15 \times 50) = 4{,}570 \text{ kilogs. per sq. cm.}$$

These are rough working formulas that, while often departed from in fact, and while purely empirical, may prove of some value in framing specifications. The formula for the value of T_m fails with alloys containing less than 1 *per cent. tin*, as the strength then rapidly falls to $t = 0$.

The table which follows will present, in convenient form, probably fair minimum values to be expected when good foundry work can be relied upon, and may ordinarily be used in specifications with the expectation that a good brass-founder will be able to guarantee them.

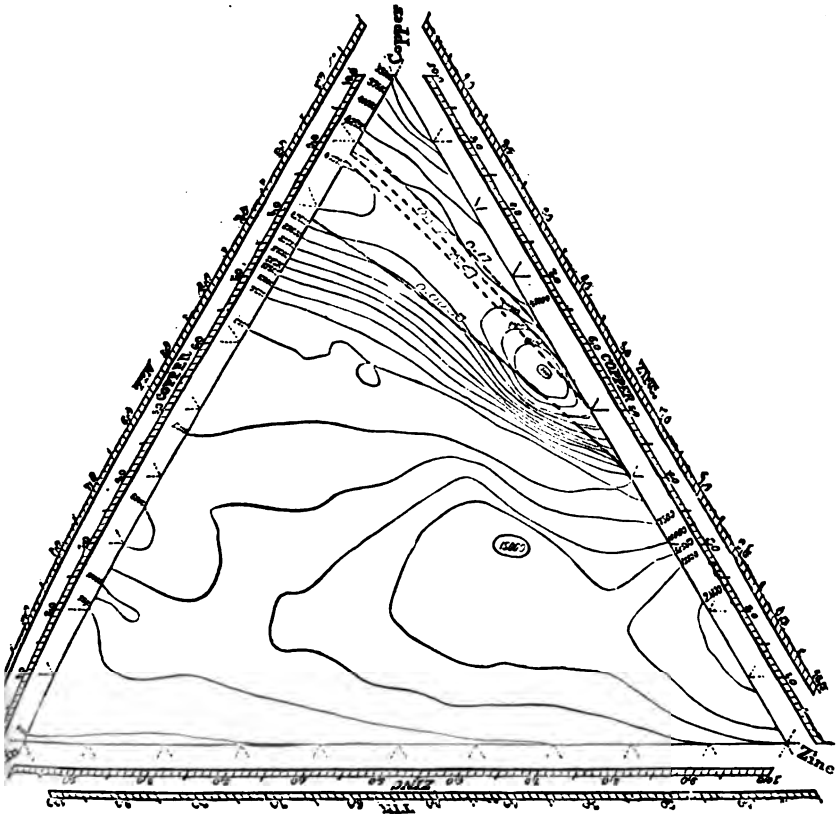
MINIMUM TENACITY OF ALLOYS.

ALLOY.			TENACITY.—Probable Minimum.	
Cu.	Zn.	Sn.	Lbs. per sq. in.	Kgs. per sq. cm.
100	0	0	30,000	2,109
95	5	0	32,500	2,285
90	10	0	35,000	2,460
85	15	0	37,500	2,636
90	0	10	40,000	2,812
95	0	5	35,000	2,460
97½	0	2½	32,500	2.285
90	5	5	37,500	2,636
85	10	5	40,000	2.812
75	20	5	45,000	3,163
68	30	2	47,000	3,304
64	35	1	48,500	3.410
60	40	0	50,000	3,515

Ductility.—The ductility of these alloys is a subject of as much interest to the engineer as their strength; and in this quality the ternary alloys are as variable as in every other. Referring again to the map, Figure 80, it is seen that a closely grouped set of slightly curved and slowly converging lines cross it from tin = 25, to zinc = 55, the mean line having an equation nearly $2.2t + z = 55$. Along this line the alloys have immense tenacity, as exhibited by the fact that some of them, if not nearly all, are too hard to be cut by steel tools, and in shaping them only grinding tools—either the emery wheel or the grindstone—could be used, and even then with most unsatisfactory results. Yet such was the brittleness of these metals that no reliable test of their strength could be obtained. The strain-diagrams obtained were straight, and nearly vertical lines, terminating suddenly, when the piece snapped, without indication of approach to an elastic limit. They were perfectly elastic up to the point of fracture, but were so destitute of resilience that no use can probably be made of them by the engineer. Their brittleness was such that they would often break in the mould by contraction in

cooling, although cast in a straight bar. In some cases they crack by the heat of the hand, and were broken at one end by the jar transmitted from a light blow struck at the other end.* The border line of this valueless territory is shown

FIG. 83.—DUCTILITY OF COPPER-TIN-ZINC ALLOYS.



on the map by a slightly curved dotted line to which a line having the equation $2.5t + z = 55$ is nearly tangent. The alloys lying along this line have nearly equal ductility, extending, according to measurements obtained by the autographic machine, about .03 of one per cent.

* Report to U. S. Board.

Above this line is another having nearly the equation $4t + z = 50$, which last line is that of equal ductility for alloys exhibiting extensions of 3 per cent. Still nearer the "pure copper corner" is a line fairly representing alloys containing about $3\frac{3}{4}t + z = 48$, and along which the extensions were 7.3 per cent., and another such line extending from standard gun-metal compositions on the one side to Muntz metal on the other—Cu 90, Sn 10, to Cu 55, Zn 45,—of which the equation is nearly $4.5t + z = 45$, represents alloys averaging an extension of 17 per cent. These lines are best seen on the sheet of extensions, Fig. 83. All alloys lying above the line taken here as a boundary line give figures for tenacity that exceed 30,000 pounds per square inch (2,109 kilogs. per sq. cm.).

The addition of tin and of zinc to cast copper thus increases tenacity at least up to a limit marked by the line $3t + z = 55$; but the influence of tin is nearly twice as great as that of zinc, and the limit of useful effect is not reached in the latter case until the amount added becomes very much greater than with the former class—the copper-tin alloys. Brasses can be obtained which are stronger than any bronzes, and the ductility of the working compositions of the former class generally greatly exceeds that of the latter. Ternary alloys may be made containing about $4t + z = 50$, which exceed in strength any of the binary alloys, and compositions approaching copper, 55; tin, 2; zinc, 43; may be made, of extraordinary value for purposes demanding great strength, combined with the peculiar advantages offered by brass or bronze. The addition of one-half per cent. tin to Muntz metal confers vastly increased strength.

The range of useful introduction of tin is thus very much more restricted than that of zinc; alloys containing 12 to 15 per cent. tin are so hard and brittle as to but rarely find application in the arts, while brass containing 40 per cent. zinc, is the toughest and most generally useful of all the copper-zinc "mixtures." The moduli of elasticity of these alloys are remarkably uniform, more than one-half of all those here described ranging closely up to fourteen millions, or one-half that of well-made steel-wire. The moduli gradually and

slowly increase from the beginning of the test to the elastic limit.

The Fracture of these Alloys is always illustrative of their special characteristics. Those broken by torsion in the autographic testing machine were, if brittle, all more or less conoidal at the break; ductile alloys yield by shearing in a plane at right angles to the axis of the test piece; the former resemble cast iron and the latter have the fracture of wrought iron. Every shade of gradation in this respect is exhibited by an observable modification of the surface of fracture varying from that characteristic of extreme rigidity and brittleness, through an interesting variety of intermediate and compound forms to that seen in fracture of the most ductile metals.

Possibilities of Improvement.—The tenacities and ductilities given are within the best attainable figures where they relate to the most valuable working bronzes and brasses. These figures represent the result of ordinary founders' work; and metals rich in copper, made with no greater precaution against oxidation and liquation than is usual in brass foundries, may be vastly improved by special treatment suggested, by using pure ingot metals, fluxing carefully, as with phosphorus or manganese, casting in chills, rapid cooling, and finally rolling, or otherwise compressing, either hot or cold.

Unannealed copper wire is reported by Baudrimont* as having a tenacity of about 45,000 pounds per square inch (3,163 kilogs. per sq. cm.), and Kirkaldy reports 28.2 tons per square inch (63,168 pounds per square inch, 4,440 kilogs. per square cm.), the wires having diameters of 0.0177 and 0.064 inches (0.044 and 0.165 cm.) respectively.

A way should be found to secure equal purity, homogeneousness, and density in cast copper, and such metal should then possess tenacity and toughness equal to that of rolled metal. Gun-bronze, which ordinarily has a tenacity of about 35,000 pounds per square inch (2,460 kilogs. per sq. cm.) has been made at the Washington Navy Yard.

* Annales de Chimie, 1850.

Alloys to be hammered or rolled will be found more difficult to work as the percentage of tin is increased, and the minutest addition of tin to the brasses usually rolled is found to sensibly decrease their manageability.

The "Maximum Bronzes" form a group demanding special consideration as including a collection of generally unfamiliar but exceptionally valuable alloys.

The work planned by the Author in the investigation of this part of the subject was left incomplete by the U. S. Board, but was continued, as opportunity offered, at intervals up to the present time.* The position and characteristics of the strongest possible alloys of the three metals constituting the "Kalchoids" having been determined with a fair degree of accuracy, as already described, the next step was to ascertain what modifications might be produced in them by careful fluxing and the use of still more carefully prepared alloys. This later study was made in the years 1882–3, in the same manner as the earlier investigations for the U. S. Government, at the suggestion and under the supervision of the Author, by Mr. W. E. H. Jobbins, whose report is here abridged.†

The area chosen as the field of this investigation was a small triangular portion surrounding the peak of the mountain, Fig. 81, marked 65,000 on Fig. 80, as this area embraces all that portion of the field in which the most valuable alloys had been proven to be located. The data obtained gave exceedingly high figures, the lowest average value of tenacity being above 50,000 pounds per square inch (3,515 kilogs. per sq. cm.). As this research extended over a very limited area, it was possible to conduct the investigation with much greater exactness than before, and thus settle the composition of the "strongest of the bronzes."

The metals varied with differences of but one per cent.; 23 combinations were chosen; 2 test-pieces were made of each

* The U. S. Board was strangled by refusal of appropriations, leaving the work in hand unfinished. Some of the work necessary to the presentation of the reports actually made was, however, concluded by the Author, at some expense, in the Mechanical Laboratory of the Stevens Institute of Technology.

† "Investigation Locating the Strongest of the Bronzes," J. F. I., 1884.

composition, making 46 test-pieces. Usually, the data obtained from two specimens of the same composition agreed so closely that the average value was safely taken; but, when there was a marked difference, the data agreeing more closely with the results anticipated from analogy were adopted, and the other value rejected as being probably erroneous. The copper employed was from Lake Superior, the zinc from Bergen Port.

In the use of tin, phosphorus was added to give soundness in these copper-tin and copper-tin-zinc alloys, which are so liable to be made seriously defective by the absorption of oxygen and the formation of oxide. It has been found possible to produce, on a commercial scale, an alloy of phosphorus and tin, which, while containing a maximum percentage, does not lose phosphorus when remelted. The best proportions for practical purposes are said to be tin 95 per cent. and phosphorus 5 per cent.

After careful study, the following limits of the field were decided upon: Copper, maximum 60, minimum 50; Zn, 48 and 38; Sn, 5 and 0. These limits include the best alloys for purposes demanding toughness as well as strength.

The compositions are given in the following table:

BEST COPPER-TIN-ZINC ALLOYS, OR KALCHOIDS.

NO.	CU.	ZN.	SN.	NO.	CU.	ZN.	SN.	NO.	CU.	ZN.	SN.
1	55	43	2	9	53	43	4	17	58	40	2
2	54	44	2	10	55	41	4	18	54	45	1
3	54	43	3	11	57	41	2	19	53	44	3
4	55	42	3	12	57	43	0	20	54	42	4
5	56	42	2	13	55	45	0	21	56	41	3
6	56	43	1	14	52	46	2	22	57	42	1
7	55	44	1	15	52	43	5	23	58	41	1
8	53	45	2	16	55	40	5				

The castings were made much as in all the earlier investigations, the same precaution being taken to prevent volatilization of zinc, and care was taken to secure rapid cooling to prevent liquation. All the compositions thus made were

strong and usually tough; all could be turned and worked safely, and all were evidently of commercial value for the purposes of the engineer. All test-pieces were sound, and even microscopic examination revealed no defects in structure. The investigation was made by the use of the Author's autographic machine as permitting most rapid work and most exact determinations of quality and behavior, especially as to the latter near the elastic limit. The samples were all reduced to the standard form and size.

Results of Tests.—The formula used is $M = wh + f$; where w = moment necessary to deflect the pencil one inch; h = height of the curve above the base line at θ_r, f = friction in foot-pounds, and M is the total torsional moment.

In this case, $w = 96.93$ foot-pounds, and $f = 4.75$, h being measured on the strain-diagram of each test-piece. To obtain the required values of T the formula $T = [300 - \frac{1}{3}\theta_r]\ M$,* in which M is known, and θ_r is measured directly from the autographic record; T is the calculated tenacity. The values of M, T, θ_e and θ_r, the total moment, the approximate tenacity, and the angles of torsion at the elastic limit and at rupture, have been included in the following table:

STRENGTH OF BEST COPPER-TIN-ZINC ALLOYS OR KALCHOIDS.

ORIGINAL MARK.		STRESS IN TORSION. FOOT-POUNDS. M.		APPROXIMATE STRESS IN TENSION. FOOT-POUNDS. T.		ANGLES.	
		Ultimate.	Average.	Ultimate.	Average.	θ_e	θ_r
I X I	A	270.208	261.065	77,309	74,805	1.5°	43°
	B	251.922		72,301		1	40
O B	A	178.321	193.369	53,946	56,653	1.1	5.05
	B	208.400		59,810		0.7	40
Z 3	A	251.922	235.929	75,576	70,778	1	13.77
	B	219.935		65,980		1	10
J 4	A	243.392	250.851	73,017	73,965	2	19.8
	B	258.319		74,912		2	30.3

* This relation between torsional and tensional resistances was obtained by experiment on the machine used in this investigation. Trans. Am. Soc. C. E., no. clxiii., vol. vii., 1878.

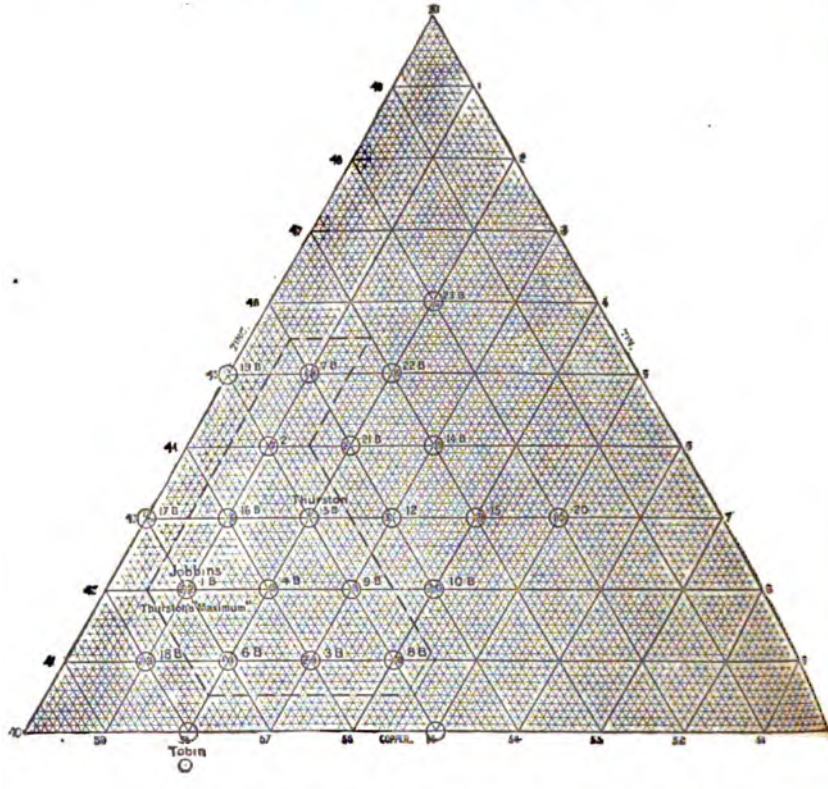
ORIGINAL MARK.		STRESS IN TORSION. FOOT-POUNDS. *M.*		APPROXIMATE STRESS IN TENSION. FOOT-POUNDS. *T.*		ANGLES.	
		Ultimate.	Average.	Ultimate.	Average.	θ_c	θ_r
F 5	A	268.881	266.212	75,824	75,467	4.6°	55°
	B	263.543		75,109		2	46
G 6	A	227.689	224.151	64,208	63,700	2.05	53.3
	B	220.612		63,193		2	42.1
K 7	A	286.847	268.851	80,910	75,826	2	54
	B	250.855		70,741		2	53
R 8	A	194.634	189.488	58,390	56,844	2	9.1
	B	184.331		55,299		2.69	5 72
S 9	A	222.853	226.725	66,853	68,017	1.5	5.78
	B	230.597		69,179		1.79	4.5
L 10	A	249.014	250.948	74,704	75,284	2.1	4.6
	B	252.881		75,864		2.8	8.8
Z 11	A	260.645	249.014	74,269	69,116	2.4	39.8
	B	237.382		63,964		1.9	35
D B	A	227.689	234.474	61,020	61,390	2.3	95.2
	B	241.259		61,762		1.6	131.4
M 13	A	227.689	217.996	64,208	61,058	2	52.4
	B	208.303		57,908		1.1	65
U 14	A	163.715	170.450	49,113	51,139	2.3	4.9
	B	177.185		53,155		2	7.2
V 15	A	189.886	208.788	56,965	62,636	2.6	4
	B	227.689		68,306		2	5
N 16	A	225.750	239.974	67,725	71,842	1.6	3.8
	B	253.198		75,959		1.6	6.8
A 17	A	227.689	238.771	63,200	68,344	1.4	54
	B	250.952		73,488		1.8	43.2
P 18	A	254.829	259.737	72,871	72,186	1.6	43.4
	B	260.645		71,501		1.8	54
T 19	A	231.566	214.119	69,459	64,230	2 2	8
	B	196.671		59,001		1.4	4.8
Q B O	A	229.628	244.168	68,888	73,250	1.6	6.4
	B	258.707		77,612		1.8	7.2
H B I	A	283.908	266.768	81,381	75,135	2.9	38
	B	229 628		68,888		2.4	8
E B B	A	305.233	263.508	85,770	73,378	2	56
	B	221.773		60,986		2.5	76
B 33	A	225.750	200.499	63,084	54,061	1 6	63
	B	175.247		45,038		1.2	128

The neck subjected to distortion is in all cases, one inch (2.54 cm.) long between shoulders and 5/8 inch (1.5875 cm.) in diameter.

Experiments thus made proved, notwithstanding the pre-

cautions taken in making these alloys, to be a matter of some difficulty to decide satisfactorily the relative positions of the alloys studied. Nos. 7 and 22 were the best alloys made.

FIG. 84.—STRONGEST OF BRONZES.



Conclusions. The Strongest Bronzes.—The results obtained from this investigation are well exhibited in the accompanying diagram, Fig. 84. It was concluded that the alloy numbered 22 was what the Author has called the "strongest of the bronzes," and that its composition (Cu, 57; Sn, 1; Zn, 42) should locate the peak seen in the model, Fig. 81, and on the map, Fig. 80. No. 5, however (Cu, 56; Sn, 2; Zn, 42), is likely to prove a more generally useful alloy in consequence

of its greater ductility and resilience; and alloys with a little less tin may often prove even better than that. The Author has called the compositions, copper, 58 to 54; tin, ½ to 2½; zinc, 44 to 40, which may be considered as representative of a group having peculiar value to the engineer, the "*maximum bronzes.*" This cluster lies immediately around the peak seen on the model, Fig. 81, including the point of maximum altitude. The safest alloys under shock are those containing the smallest quantities of tin.

The Conclusions reached after concluding the investigations which have been described in the present chapter are confirmed by the fact that a number of single compositions have been independently discovered by other experimenters, accidentally or incidentally to special investigations, which have peculiarly high tenacity, all of which approximate more or less closely, in their proportions, to these "maximum" bronzes and *strongest* "Kalchoids."

Thus, Mr. Farquharson, president of the Naval (British) Commission, proposed, in 1874, an alloy composed of 62 parts of copper, 37 parts of zinc, and one part of tin. This is the reglementary naval alloy. When cast in bars it has shown on test a resistance of 70,000 pounds per square inch (5,000 kilogs. per sq. cm.). It rolls and works well, can be hammered into sheets, and is fusible only above red heat. It may be used as a lining for engine-pumps. It is but slightly oxidizable, and is not sensibly attacked by sea water, as shown by experiments with it extending over a period of years. A slight loss of zinc during melting must be taken into account. The British naval bronze for screw-propellers, stern bearings, bow-castings, and similar work, is composed of copper, 87.65; tin, 8.32; zinc, 4.03, and is reported to have a tenacity of 15 tons per square inch (2,362 kilogs. per sq. cm.), and to average 13½ tons (2,126 kilogs.) in good castings. Tobin's alloy, already described, is one of the "maximum" bronzes, also, containing copper, 58.22; tin, 2.30; zinc, 39.48. Sterro-metal is always a brass of nearly the same proportions of copper and zinc, *i.e.*, a Muntz metal, containing from a fraction of 1 per cent. to sometimes 2 per cent. of tin, as well as some iron.

The bronze used for journal bearings in the U. S. Navy contains copper, 88; tin, 10; zinc, 2. The strongest U. S. copper-tin-zinc alloy is that discovered by Mr. Tobin and described by the Author in earlier articles, and, as has been stated, had a tenacity of 66,500 pounds per square inch of original section, and 71,378 per square inch of fractured area (4,575 and 5,019 kilogrammes per sq. cm.) at one end of the bar, which was, as usual, cast on end, and 2 per cent. more at the other. This, like the "maximum alloy," was capable of being forged or rolled at a low red heat or worked cold. Rolled hot, its tenacity was 79,000 pounds (5,553 kilogs. per sq. cm.), and when cold-rolled, 104,000 (7,311 kilogs.). It could be bent double either hot or cold, and was found to make excellent bolts and nuts.

These and other compositions which have been occasionally introduced as having extraordinary strength and exceptional value, all contain a small amount of tin, and invariably fall within the field mapped out as described in this chapter as that containing the kalchoids of maximum possible strength. The latter, the "maximum alloys," as the Author has called them, will probably be very generally, if not exclusively, used when alloys are required of peculiar strength. It will be found that they are capable of improvement by fluxing with phosphorus, by mechanical treatment, and by small doses of iron and other metals, as are the more familiar bronzes and brasses.

CHAPTER XVI.

TEMPERATURE AND TIME AS AFFECTING THE IRONS; FLOW OF METALS; FATIGUE; WOHLER'S LAW; LAUNHARDT'S FORMULA.

The Effect of Heat and of variations of temperature upon the mechanical properties of metals has long been a subject of debate, and one which has not yet been satisfactorily settled by experiment.*

In general, it would appear that, in a perfectly homogeneous material, entirely free from internal strain, change of temperature would produce an alteration of strength and of ductility which would both be the reverse in direction of the variation of temperature.

The forces acting to produce mechanical changes being cohesive force, on the one hand, resisting external forces tending to produce distortion or rupture, while the force produced by the energy of heat-motion conspiring with external force to produce that distortion, and the molecules being at every instant in equilibrium between the force of cohesion on the one side, and the sum of the other two forces mentioned on the other, variations of form must ensue with every change in the relative magnitudes of these forces. A change of temperature produced by an increment of heat energy produces a reduction of cohesion by separation of particles, and the opposite change must cause an increase of cohesion by their approximation. Increase of temperature, by reducing the range of action of cohesion, by separating the particles and causing them to approach the limit of reach of cohesive force, reduces ductility, and the opposite change of temperature increases extensibility.

* This chapter contains some new matter and some extracted from a paper read by the Author before the Am. Society of Civil Engineers, 1874, and from a paper "On Molecular Changes in Iron," published in the *Iron Age*, 1873.

Mr. Jouraffsky has recently experimented upon rails cold (− 16° to − 21° C., + 3° to − 6° F.), and warm.

The total of the three hardening elements are expressed in phosphorus units thus: For rails which stood the test, 19 units; for rails which broke under the same test, 31 units. In the first, the units vary from 16 to 22 (in one case only 25 being reached), and in the second, the difference was from 22 (and that only in two cases, all the others being higher) to 45 units. Reports from Russian railways have shown that 77 per cent. of the breakage of rails and tires occurs on those roads at a temperature below 32° Fahr. (0° Cent.).

The variation of strength of iron with rising temperature has been studied by Kollmann, using metal of the following composition:

	WELD-IRON.	WELD-IRON.	INGOT IRON.
C	0.10	0.12	0.23
Si	0.09	0.11	0.30
P	0.34	0.20	0.09
S	0.03	trace	0.05
Mn	0.07	0.14	0.86
Cu	0.07	0.06	0.07
Fe	99.30	99.36	98.40

These metals were rolled at temperatures varying from a maximum of 2,417° Fahr. (1,325° Cent.) at the roughing rolls, to 1,112° Fahr. (600° Cent.) as a minimum at the last pass. The results of the test of finished iron at various temperatures were the following, and the steel nearly the same in method of variation, although about 50 per cent. higher in tenacity at each point:

Temperature,							
Cent.	0°	200°	300°	400°	600°	1,000°
Fahr.	32°	392°	572°	752°	1,112°	1,832°
Lbs. per sq. in.	53,300	52,600	47,900	38,950	9,860	112
Tenacity, kgs. per sq. cm.	3,750	3,570	3,370	2,734	690	8

The elastic limits decrease in nearly the same proportion. The extensions increase slowly up to the red heat.

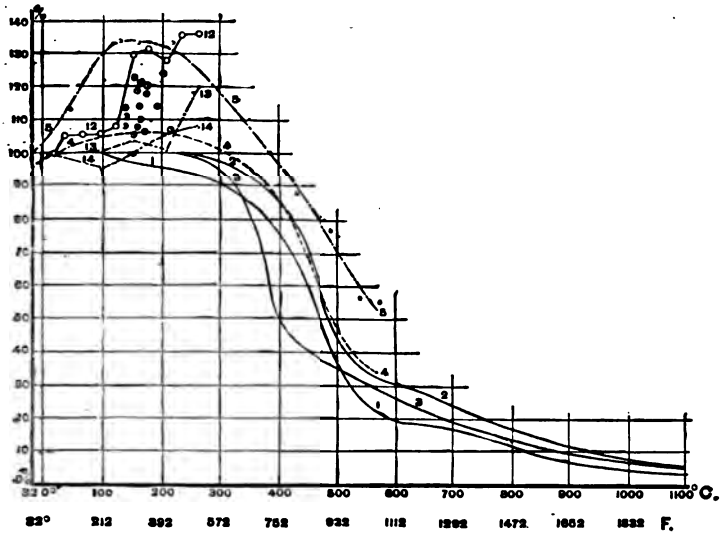


FIG. 85.—HEAT VS. TENACITY.

The diagram above* (Fig. 85) graphically represents the results of several series of experiments, some of which have not been described. It exhibits the general accordance of all later investigations with that of the Franklin Institute of 1835.

Curves Nos. 1 and 2 represent Kollmann's experiments on iron, and 3 on Bessemer "steel." No. 1 is ordinary, and 2 steely puddled iron.

Curve No. 4 represents the work of the Franklin Institute on wrought iron.

Curve No. 5 gives Fairbairn's results, working on English wrought irons.

Nos. 6 to 11 are Styffe's, and represent the experiments made by him on Swedish iron. The numbers do not appear, as these results do not fall into curves; these results are indicated by circles, each group being identified by the peculiar filling of the circles, as one set by a line cross.

* *Eisen und Stahl*, A. Martens; *Zeitschrift des Vereins Deutscher Ingenieure*; Feb. 1883, p. 127.

ing the centre, another by one across, a third by a full circle, etc.

The broken lines, 12 and 13, are British Admiralty experiments on blacksmiths' irons, and No. 14 on Siemens steel.

The first five series, only, are of value as indicating any law; and they exhibit plainly the general tendency already referred to, to a decrease of tenacity with increase of temperature.

Fairbairn's experiments, No. 5, best exhibit the maximum, first noted by the Committee of the Franklin Institute, at a temperature between that of boiling water and the red heat.

It will be observed that the measure of tenacity, at the left, is obtained by making the maximum of Kollmann unity. It will also be noted that Kollmann does not find a maximum as in curves 4 and 5, but, on the contrary, a more rapid reduction in strength at that temperature than beyond.

It would seem, therefore, that that peculiar phenomenon must be due to some accidental quality of the iron. The Author has attributed it to the existence in the iron, before test, of internal stresses which were relieved by flow as the metal was heated, disappearing at a temperature of 300° or 400° Fahr. (149° to 204° Cent.).

A singular modification of set by change of temperature was noted while testing springs in the mechanical laboratory of the Stevens Institute of Technology;* tested at 32° Fahr. (0° Cent.) the set of a coil of ⅝ inch (1.59 centimetres) wire, twenty inches (50.8 centimetres) long, after a compression of 3½ inches (8.9 centimetres) under a load of 5,000 pounds (2,268 kilogrammes) was 0.188 inch (0.48 centimetre), while at 212° Fahr. (100° Cent.) it was but 0.016 inch (0.04 centimetre).

The experiments of Mr. Oliver Williams,† in determining the change produced in the character of the fracture of iron by transverse strain, at extreme temperatures, indicate loss of ductility at *low* temperatures.

Two specimens of nut iron, from different bars, made at

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* *Van Nostrand's Mag.*, 1878, p. 528. De Bonneville.

† *The Iron Age*, New York, March 13, 1873, p. 16.

Catasauqua, Pennsylvania, were first nicked with a cleft on one side only, and then broken under a hammer, at a temperature of about 20° Fahr. (— 7° Cent.). At this temperature, both specimens broke off short, showing a clearly defined granular, or steely iron fracture. The pieces were then gradually heated to about 75° Fahr. (24° Cent.), and then broken as before, developing a fine, clear, fibrous grain. The two fractures were but four inches (10.16 centimetres) apart, and are entirely different. The accompanying illustrations, from the Author's collection, exhibit this case.

FIG. 86.—FRACTURE AT ORDINARY TEMPERATURE.

It has been long known that a granular fracture may be produced by a shock, in iron which appears fibrous when gradually torn apart. This was fully proven by Kirkaldy.* Mr. Williams was, probably, the first to make the experiment just described, and thus to make a direct comparison of the characteristics of fracture in the same iron at different temperatures.

FIG. 87.—FRACTURE AT LOW TEMPERATURE.

Valton has found † that some iron becomes brittle at temperatures of 572° or 752° Fahr. (300° to 400° Cent.), and regains ductility and toughness at higher temperatures. On the whole, the fracture of iron at low temperatures has been found to be charac-

*Experiments on Iron and Steel. † *Bulletin Iron and Steel Assoc.*, Feb. 1877

teristic of a brittle material, while, at higher temperatures, it exhibits the appearance peculiar to ductile and somewhat viscous substances. The metal breaks, in the first case, with slight permanent set, and a short, granular fracture, and in the latter with, frequently, a considerable set, and the form of fracture indicating great ductility. The variation in the behavior of iron, as it approaches the welding heat, illustrates the latter condition in the most complete manner.

The effect of alteration of temperature upon cast iron has been less studied than its influence on the malleable metals. The few experiments made by the Author indicate greater susceptibility to the influence of heat than is observed in either wrought iron or steel. The accompanying diagram exhibits this comparison, as made by the use of the Autographic Testing Machine.*

In these experiments the testing machine was placed in the open air in mid-winter, and exposed with test piece under stress to temperatures falling as low as — 10° Fahr. (— 23° Cent.), and, again, taken indoors, and the tests continued at temperatures rising to + 70° Fahr. (+ 21° Cent.). In the diagram, the horizontal scale at the top is a scale of temperatures, several points, as 70°, 25°, 18°, 10°, being marked; the vertical scale is one of tenacities. The several numbers attached at the extremities of the curves are those of the specimens tested. It will be noted that

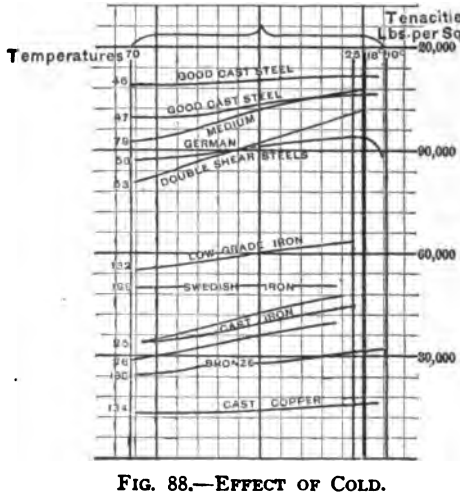

FIG. 88.—EFFECT OF COLD.

* *Trans. Amer. Soc. C. E.*, 1874; *Jour. Franklin Inst.*, 1874, Vol. LXVII., Pl. III.

cast iron shows greater loss of tenacity, at the higher temperatures than other metals, except a single piece of double shear steel.

Swedish iron seems almost unaffected, and cast copper is but slightly weakened. The effect of change of temperature is invariably, so far as observed, to produce a change of tenacity in the opposite direction, rise in temperature being accompanied by a decrease of strength and *vice versa.*

Valton found that a steel rod bent very well at a temperature a little below dull red, but broke at a temperature which may be called blue, the fracture showing that color. Portions of the rod which were below this temperature manifested much toughness, and bent without fracture. Charcoal pig iron from Tagilsk, made in 1770, irons obtained from the Ural in rods and sheets, soft Bessemer and Martin steels from Terrenoire, soft English steel and good English merchant bars, all gave the same results, whether the metal tested had been hammered or rolled. Valton found that the phenomenon had been long known to the workmen under his direction. In working sheet iron with the hammer, they wait until the metal had cooled further when approaching the temperature which would give the blue fracture when broken.

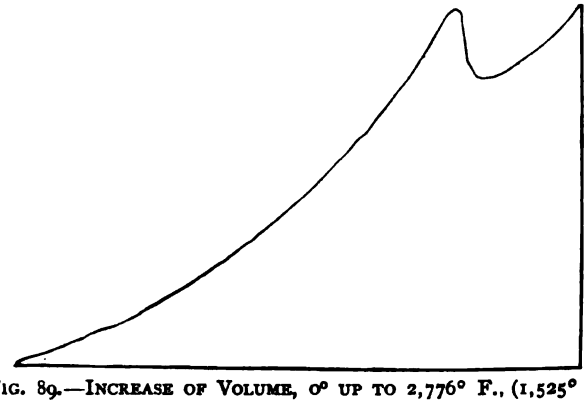

FIG. 89.—INCREASE OF VOLUME, 0° UP TO 2,776° F., (1,525° C.).

He concludes that wrought iron, as well as some kinds of soft steel, even when of excellent quality, are very brittle at

a temperature a little below dull red heat—577° to 752° Fahr. (between 300° and 400° Cent.).

The variation of strength follows quite closely the change of density, which latter is illustrated in the preceding diagram, which exhibits increase of volume from the freezing point.

The sudden fall of the line before reaching the melting point indicates the sudden increase of volume which castings exhibit while cooling, and which enables "sharp" castings to be secured. It is at the crest noted near this point that viscosity is observed. From this point back to the freezing point the variation follows a regular law.

Conclusions as to Effect of Change of Temperature.—It would thus seem that the general effect of increase or decrease of temperature is, with solid bodies, to decrease or increase their power of resistance to rupture, or to change of form, and their capability of sustaining "dead" loads; and we may conclude:

(1.) That the general effect of change of temperature is to produce change of ductility, and, consequently, change of resilience, or power of resisting shocks and of carrying "live loads." This change is usually opposite in direction and greater in degree at ordinary temperatures than the variation simultaneously occurring in tenacity.

(2.) That marked exceptions to this general law have been noted, but that it seems invariably the fact that, wherever an exception is observed in the influence upon tenacity, an exception may also be detected in the effect upon resilience. Causes which produce increase of strength seem also to produce a simultaneous decrease of ductility, and *vice versa*.

(3.) That experiments upon copper, so far as they have been carried, indicate that (as to tenacity) the general law holds good with that metal.

(4.) That iron exhibits marked deviations from the law between ordinary temperatures and a point somewhere between 500° and 600° Fahr. (260° and 316° Cent.), the strength increasing between these limits to the extent of about 15 per cent. with good iron. The variation becomes more marked and the results more irregular, as the metal is more impure.

Experiments upon the steel castings of which analyses have been already given illustrate well the importance of annealing such metals as are liable to internal stresses, thus:

EFFECT OF ANNEALING STEEL CASTINGS.

TREATMENT.	ULTIMATE STRENGTH.		ELONGATION.
	Lbs. per square inch.	Kilogrammes per square centimetre.	Per cent.
Not annealed	89,289	6,177	4
Annealed.....	104,362	7,337	8
Not annealed	71,904	5,055	4.16
Annealed.....	81,984	5,763	14.6
Not annealed	53,782	3.781	1
Annealed.....	63,616	4,572	13
Not annealed	99,496	6,995	2
Annealed.....	98,560	6,929	12
Not annealed	71,944	5,258	1.65
Annealed.....	107,744	7,574	7.2
Not annealed	67,200	4,724	13.3
Annealed.....	67,296	4,731	27.5

The Author has found, during an investigation extending from some time in 1881 to date, that annealing renders iron wire subject to a gradual yielding under permanent loads much less than those determined by ordinary test. The difference in this respect between the annealed and the hard, unannealed wire from the draw-plate was remarkably great.

Professor Abel concludes, after a careful investigation, that the condition of the carbon in steel determines its condition as to hardness; that in annealed steel, the carbon exists

as a definite carbide of iron, which is found in smaller proportion as steel is hardened. Professor Hughes, studying the magnetic condition of the steel, concludes it to be an *alloy* of carbon and iron, the carbide described by Abel being broken up, on hardening, to form this alloy.*

Effect of Age and Exposure.†—There are many phenomena which cannot be conveniently exhibited by strain diagrams; such are the molecular changes which occupy long periods of time. These phenomena, which consist in alterations of chemical constitution and molecular changes of structure, are not less important to the mechanic and the engineer than those already described. Requiring usually, a considerable period of time for their production, they rarely attract attention, and it is only when the metal is finally inspected, after accidental or intentionally produced fracture, that these effects become observable.

The first change to be referred to is that gradual and imperceptible one which, occupying months and years, and under the ordinary influence of the weather going on slowly but surely, results finally in important modification of the proportions of the chemical elements present, and in a consequent equally considerable change of the mechanical properties of the metal.

Exposure to the weather, while producing oxidation, has another important effect: It sometimes produces an actual improvement in the character of the metal.

Old tools, which have been laid aside or lost for a long time, acquire exceptional excellence of quality. Razors which have lost their keenness and their temper recover when given time and opportunity to recuperate. A spring regains its tension when allowed to rest. Farmers leave their scythes exposed to the weather, sometimes from one season to another, and find their quality improved by it. Boiler makers frequently search old boilers carefully, when reopened for repairs after a long period of service, to find any tools that

* Trans. Inst. Mechanical Engineers of G. B., 1883.

† *Journal of the Franklin Institute*, June, 1875. *Scientific American*, March 27; 1875.—R. H. Thurston.

may have been left in them when last repaired; which, if found, are almost invariably of improved quality. The Author, when a boy, amusing himself in the shop, if denied the use of their tools by the workmen, looked about the scrap-heaps and under the windows for tools purposely or carelessly dropped by the workmen; and when one was found badly rusted by long exposure, it usually proved to be the best of steel. A most striking illustration of this improvement of the quality of wrought iron with time has come to the knowledge of the Author. The first wrought-iron T-rails were designed by Robert L. Stevens, about the year 1830, and were soon afterward laid down on the Camden and Amboy Railroad. These, when put down, were considered, and actually were, brittle and poor iron. Many years later, some still remained on sidings. Some of these rails were taken up and re-rolled into bar iron. The long period of exposure had so greatly changed the character of the metal that the effect was unmistakable.

There are probably, as the Author has concluded, two methods of improvement, each due to an independent molecular action. In the case of the razor and the spring, which regain their tempers when permitted to rest, a molecular rearrangement of particles, disturbed by change of temperature in one case and by alternate flexing and relaxing in the other, probably goes on, much as the elevation of the elastic limit and the increase of resisting power, discovered by the Author and shown on the strain diagram, takes place under strain and set. The other cases may probably be due to a combination of this physical change with another purely chemical action, which is illustrated best in the manufacture of steel by the cementation process. Here the element carbon enters the solid masses of iron, and diffuses itself with greater or less uniformity throughout their volume. There seems to exist a tendency to uniform distribution which is also seen in other chemical changes. Many chemical processes are accelerated, checked, and even reversed by simple changes of relative proportions of elements.

When, therefore, wrought iron containing injurious ele-

ments capable of oxidation, is exposed to the weather, the surface may be relieved by the combination of these elements with oxygen, and the surcharged interior, by this tendency to uniform diffusion, is relieved by the flow of a portion to the surface, there to be oxidized and removed. This process goes on until the metal, after lapse of years, becomes comparatively pure. Meantime, the occurrence of jarring and tremor, such as rails are subjected to, may accelerate both this and the previously described change.

Crystallization.—The effect of strains frequently applied, during long intervals of time, is quite different, however, where they are so great as to exceed the elastic range

FIG. 90.—FRACTURED SURFACE OF CONNECTING ROD.

of the material. The effect of stresses which strain the metal beyond the elastic limit has already been referred to.

A still more marked case has come to the notice of the writer. The great testing machine at the Washington Navy Yard has a capacity of about 300 tons, and has been in use 35 years. Quite recently, Commander Beardslee subjected it to a stress of 288,000 lbs. (130,000 kilogrammes), which stress had frequently been approached before; but it subsequently broke down under about 100 tons. The connecting bar which gave way had a diameter of five inches, and should have originally had a strength of about 400 tons (406,400 kilogrammes). Examining it after rupture, the fractured section, Fig. 90, was found to exhibit strata of varying thickness, each having a characteristic form of break. Some were quite granular in appearance, but the larger proportion were distinctly crystalline. Some of these crystals are large and well defined. The laminæ, or strata, preserve their characteristic peculiarities, whether of granulation or of crystallization, lying parallel to their axis and extending from the point of original fracture to a section about a foot distant, where the bar was broken a second time (and purposely), Fig. 91, under a steam ham-

FIG. 91.—FRACTURED SURFACE OF CONNECTING ROD.

mer. It thus differs from the granular structure which distinguishes the surfaces of a fracture suddenly produced by a single shock and which is so generally confounded with real

crystallization. This remarkable specimen has been contributed by the Navy Department to the cabinet of the Author.

In a discussion which took place many years ago before the British Institution of Civil Engineers, Mr. J. E. McConnell produced a specimen of an axle which he thought furnished nearly incontestable evidence of crystallization. One portion of this axle was clearly of fibrous iron, but the other end broke off as short as glass. The axle was hammered under a steam hammer, then heated again and allowed to cool, after which it was found necessary to cut it almost half through and hammer it for a long time before it could be broken.

While forging a large shaft for a sea-going steamer at the Morgan Iron Works, in New York, some years ago, a "porter-bar" was employed which had been in the works and in frequent use for many years. This bar was about 20 feet (6.1 metres) long, 12 inches (29.5 centimetres) in diameter at the

FIG. 92.—FRACTURED SURFACE OF LINK OF TESTING MACHINE.

small end, and 23 inches (58.4 centimetres) at the end welded to the forging. The whole mass was slung from the crane in

the usual way. While the shaft was under the hammer, the jar detached the end of the porter-bar on the free side of the sling, breaking it where it was about 15 inches (26.7 centimetres) in diameter, and entirely unstrained by the load, and detaching a piece weighing a ton or more. The load which would have been calculated as the breaking load hung upon the extreme end would have been about 14 tons (or tonnes). The fracture was partly granular, but largely crystalline. One crystal had faces a half inch (1.27 centimetres) square.

A student at the Stevens' Institute of Technology, while annealing a number of steel hammer heads, left them exposed all night to the high temperature of the air-furnace in the brass foundry. When finishing one of them, a careless blow broke it, and the fractured surface was found to possess a distinctly crystalline character.

In the illustration, Fig. 93 is a magnified representation of the surface of fracture. The two holes shown, penetrating the mass, are those drilled in the first operation, preparatory to fitting the handle. The facets of the crystals are seen to be remarkably perfect and well defined. Fig. 94 represents the hammer on very nearly the natural scale. In this example, however, the faces were nearly all pentagonal, and were usually very perfectly formed. When imperfect crystals are developed, it is easy to mistake them, but the formation of pentagonal dodecahedra, in large numbers and in perfectly accurate forms, may

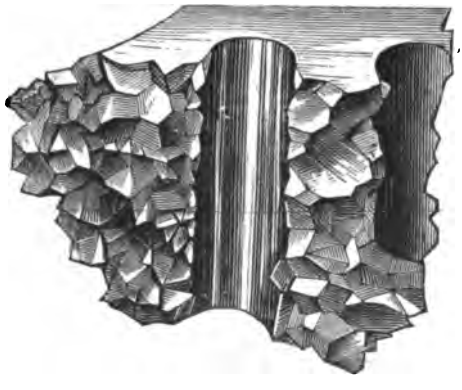

FIG. 93.—HAMMER-HEAD, MAGNIFIED.

FIG. 94.—HAMMER-HEAD, NATURAL SIZE.

be considered unmistakable evidence of the fact that iron may crystallize in the cubic, or a modified system. This may apparently take place, according to some authorities, either by very long continued jarring of the particles beyond their elastic limits, or under the action of high temperature, by either mechanical or physical tremor. But no evidence is given here that a single suddenly applied force, producing fracture, may cause such a systematic and complete rearrangement of molecules. The granular fracture produced by sudden breaking, and the crystalline structure produced as above during long periods of time, are, apparently, as distinct in nature as they are in their causes.

But simple tremor, *where no sets of particles are separated so far as to exceed the elastic range*, and to pass beyond the limit of elasticity, does not seem to produce this effect.*

In fact, some of the most striking illustrations of the improvement in the quality of wrought iron with time have occurred where severe jarring and tremor were common. As one example, the case of the wrought-iron T-rails, laid down on the Camden and Amboy Railroad in 1832, which have been already referred to, may be taken.

Here the metal has been subjected for many years to the strains and tremor accompanying the passage of trains without apparent tendency to crystallization, and with evident improvement in its quality.

Such crystallization as that last described has often been observed. Wöhler found cubic crystals in cast-iron plates which had been for some time kept at nearly the temperature of fusion in a furnace, and Augustine found similar crystals in gun-barrels; Percy found octahedra of considerable size in a bar which had been used in the melting pot of a glass furnace. Fairbairn asserts the occasional occurrence of such change due to shock, jar, and long-continued vibration. Miller found cubic crystallization plainly exhibited in Bessemer iron, which may, however, have been due to the presence of manganese. Hill shows that heat may produce such

* The Author finds such effect sometimes to follow intermitted strain.

changes in the process of manufacturing large forgings, and denies the occurrence of true crystallization in cold iron. This can only be settled by further investigation.

Dr. Sorby has examined the structure of wrought iron and of steel with the microscope, and found the hammered bloom to be a mixture of crystals of iron and portions of slag. The rolled bar, Fig. 97, contained crystals also, but they were fresh crystals formed on the cooling of the bar, and it was apparent that the fibre seen at the fracture was produced during rupture, and was not a characteristic of the unaltered iron. The cementing process of steel making was found to develop a network of flat crystals of a hard carbide of iron. Cast steel, Fig. 96, was found to contain larger crystals, of a different form, which were reduced in size by subsequent working. Meteoric iron, Fig. 95, was found to exhibit the characteristics of an iron crystallized by long exposure to a temperature beneath that of fusion.

Dr. Sorby's paper has been published with illustrations, which are reproduced in the accompanying engravings.* The samples in question comprised armor plates, meteoric iron, cast iron and cast steel, and, as an inspection will show, exhibit a greatly varying structure. The specimen of cast steel is of very uniform structure, with no lines of weakness, while an inspection of the specimen of cast iron will reveal a number of plates of graphite, that naturally tend to diminish the strength of the metal. The armor plate, on the other hand, shows varying crystals and lines of welding, while the sample of meteoric iron shows a structure altogether unlike that of any artificial iron.

Martens has used the microscope in the examination of various grades of iron and of spiegeleisen,† with somewhat inconclusive results. But he finds that certain peculiarities and characteristics, due especially to the various mechanical operations which the material undergoes, either during the process of manufacture, or molecular changes to the manner in

* J. C. Bayles, in *Iron Age* and *Mechanics*, Mch., 1883; Trans. Am. Inst. M. E., 1880.

† Verein zur Beförderung des Gewerbfleisses, 1882.

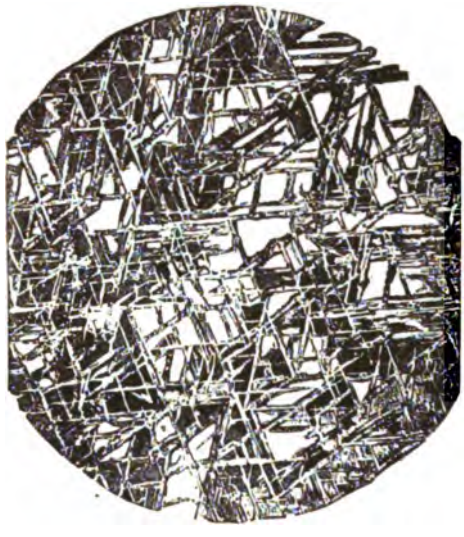

FIG. 95.—METEORIC IRON.

FIG. 96.—CAST STEEL.

FIG. 97.—ARMOR PLATE.

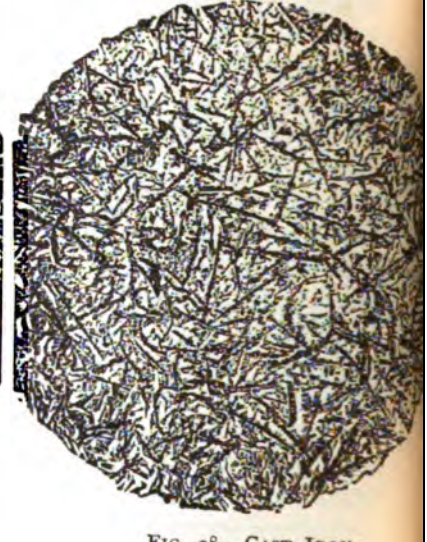

FIG. 98.—CAST IRON.

MICROSCOPIC STUDIES OF IRON AND STEEL, BY DR. SORBY.

which it is strained in performing its functions as part of a structure, can probably thus be best and most satisfactorily investigated. An examination of a specimen of gray pig iron showed that the sharp veins of graphite seldom touched the surface of the white iron. In a specimen of spiegeleisen the individual figures have a definite shape, often resembling small fir trees, which end in lines, and finally in points. Similar observations have also been made in connection with soft gray pig iron, which is distributed through the spiegeleisen. The dark portions correspond to gray pig iron, Fig. 98, while the light portions represent the spiegel.

These phenomena are undoubtedly closely connected with the crystallization of iron. The crystals of graphite consist of a series of hexagonal scales, and the flakes, as a rule, occur in a developed state only in gray pig iron, being either entirely absent in spiegeleisen, or only of rare occurrence. As shown by microscopical examinations, crystals of iron are not perfectly pure, although it has been stated that crystals having the shape which Martens calls "fir-tree crystals," actually consist of pure iron. Crystals of both gray and white iron occur together, especially in iron which contains a large proportion of manganese. Martens finds that the fractured surfaces of bars which are broken under repeated use exhibit distinctive features.

Surfaces to be examined by the microscope should be first very carefully planed up and smoothly polished; they should next be well washed with a dilute alkaline solution, to remove all greasy matter, and finally "etched" with dilute acid sufficiently to exhibit well the structure of the metal. The latter process is best practised with very dilute nitric or hydrochloric acid, exposing the surface to its action a few minutes at a time, washing with water and repeating the operation until the surface is brought into the condition in which the microscope is found to best exhibit its characteristics.

The Flow of Metals.—M. Tresca, published in *La Poinçonnage des Métaux*, some experiments on the punching of iron, using a large diameter of punch upon small thickness

of metal. His experiments were made with a punch of 1.18 inches diameter (3 centimetres) on iron plates, the greatest thickness being 0.669 inch (1.8 centimetres), and the least 0.1968 inch (0.5 centimetre). He announced, as the result of his investigations, the general law that "when pressure is exerted upon the surface of any material, it is transmitted in the interior of the mass from particle to particle, and tends to produce a flow of metal in the direction in which the resistance is least."

Experiments made with nuts or bars punched cold show that an actual flow does take place in metals under pressure, which flow is governed by some law not yet enunciated.*

As the punch entered, a flow took place, which was greatest in the width—the direction of least resistance—the length being but slightly increased; the increase was greatest on the bottom face of the block. The metal at the top was therefore compelled to spread laterally, producing increased width.

The punched block was bulged in the width, producing a curved surface, concave toward the axis, greatest at the central line of its width, and decreasing gradually in either direction as it departs from that line.

The length is also increased, but not as noticeably as the width.

FIG. 99.

Fig. 99 represents, full size, the core punched from the block, Fig. 100, it is only $1\frac{1}{8}$ inches in depth, while the hole from which it came was $1\frac{3}{4}$ inches deep. At first sight, it would seem that all the metal from the hole had been squeezed into the core, and, therefore, that its density must be increased. But the density of the block was 7.82. The core itself had a density of 7.78.

The density of the block is slightly more than that of the core; but this difference is probably due to the density of the surface being increased by chipping and filing, and also to the greater soundness of the block. As the density has not increased, there must have been a flow of metal from the core into the block.

* *Journal of the Franklin Institute*, March, 1878. D. Townsend.

These experiments were tried with other thicknesses; the flow seemed to decrease directly as the diameter of the hole increased, and as the thickness of the bar decreased.

In order to show to the eye the flow which had thus occurred, several of the large nuts with their cores were planed in half. The resulting rectangular faces being brightly polished and perfectly clean, were then etched with acids of various strengths, when they presented the appearances of Figs. 100 and 101.

FIG. 101.

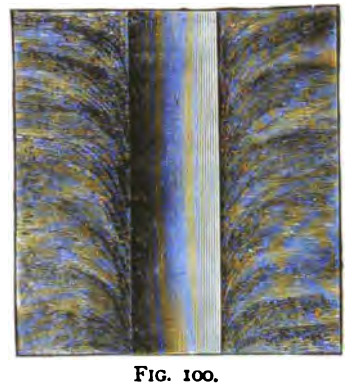

FIG. 100.

The curved lines mark the laminæ, or plates, which were piled and rolled together to make up the bar. It will be noticed that they all curve downward, and that the greatest curvature occurs at the top, remaining nearly constant for some distance, and then decreasing toward the bottom. The flow must have occurred when the punch first entered the bar, and continued regularly, until the pressure above parted the under face, and the core was forced out.

In the case represented in Figs. 102 and 103, the hole was punched *with* the grain, instead of *across* it, the result being that the superposed laminæ,

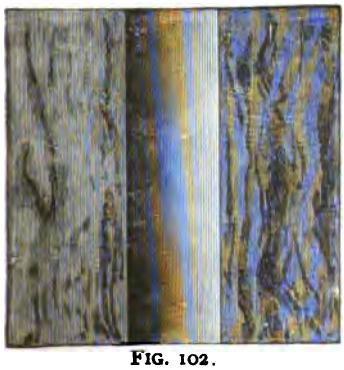

FIG. 102.

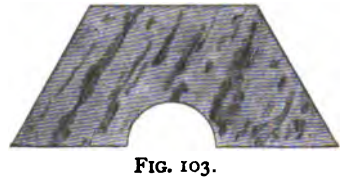

FIG. 103.

instead of being curved downward, were wrinkled or warped, from the flow and the conse-

quent pressure which took place, acting against their sides or faces.

Several experiments were tried by partially punching bars of the same thickness with punches that had the same diameter, but which varied in length according to the depth of the hole to be punched. The bars were uniformly $1\frac{1}{16}$ inches thick, and the punch $\frac{7}{16}$ inch in diameter.

In the last experiment the punch was stopped at a depth of $1\frac{1}{8}$ inches, the resulting block being shown in Fig. 105. The core projects from the bottom face nearly $\frac{1}{2}$ inch,

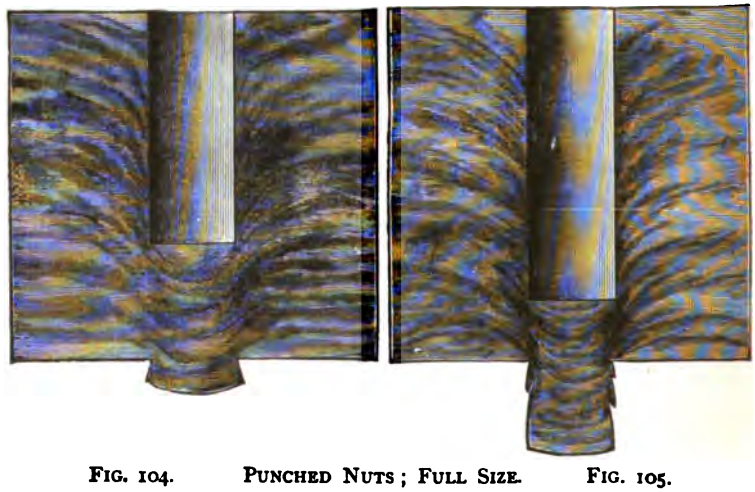

FIG. 104. PUNCHED NUTS; FULL SIZE. FIG. 105.

and measures, as before, almost $\frac{3}{4}$ inch in depth. The layers, in this case, are all severed, and the line of parting of the core from the block is plainly visible. The process of punching these thick bars does not depend for its successful performance upon the time taken, but upon the accuracy and power of the machine, and the quality of the punch. The flow remains the same, whether the motion is fast or slow.

Relief of Internal Stresses by Rest.—A method of *improvement* under such conditions as have been elsewhere described, and one which seems likely to have an effect of especial importance in castings in hardened and in tempered metals, is the gradual relief, by rest, of those internal

stresses which are induced by working malleable iron, by casting cast irons, and by tempering steel. These stresses are apparently relieved by the process of flow investigated by Prof. Henry and Mon. Tresca.

Rodman reports* the following tests of cannon tested in one case, a few days after they were cast, and in another case, more than six years later:

	S. G.	TENACITY.	ENDURANCE.
Cast in 1851 and proved same year.....	7.287	{ 37,811 / 2,658 }	72 fires.
Cast in 1846 and proved in 1852.....	7.247	{ 29.423 / 2,068 }	2,582 "
" " " " " " " "	7.220	{ 22,989 / 1,616 }	800 "

Tenacities are given in pounds per square inch, and in kilogrammes per square centimetre. Rodman calls attention to this extraordinary difference, and explains the change in the manner already indicated, illustrating it by reference to the readiness with which pieces of metal under strain conform to the new shape given them, as when hoops bent upon barrels at first lose but little of their power of restoration, but afterward take permanently the bend given them; this process being repeated, they may finally take a bend that would at first have broken them. In the case above cited, the metal of highest tenacity proved weakest under fire. Hard and strong cast iron is most liable to internal stress.

The Author tested wires from the cables of the Fairmount Suspension Bridge, at Philadelphia, when taken down after 32 years' use, and found them fully equal in tenacity and ductility to wire of similar grade just from the wire mill. This tenacity was about 90,000 pounds per square inch (6,327 kilogrammes per square centimetre); they were 0.1236 inch (0.314 centimetre) in diameter.

Iron and steel wire is found stronger and more ductile after having been kept long in stock, than if tested when first

* Report on Metals for Cannon, p. 217.

made. It is, therefore, advisable to keep all strained metals out of use as long as is possible or convenient before subjecting them to stress.

The Effect of Time under Stress is also often observable, and is frequently even important. It is not the same for all metals, or even for different specimens of the same class.

M. Vicat states that in his experiments* four wires were loaded, respectively, with $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ and $\frac{3}{4}$ their ultimate resistance, and their elongations were observed and recorded at intervals of one year.

The relative extensions observed indicated a gradual lengthening of the three which were strained beyond the elastic limit, and that most strained finally broke, after sustaining three-fourths its original ultimate breaking weight two years and nine months, the point of rupture being finally determined by the action of corrosion, which had not been entirely prevented.

The several extensions were as follows:

No. 1, sustaining $\frac{1}{4}$, 33 months.....	0.000 per cent.
No. 2, sustaining $\frac{1}{3}$, 33 months.....	0.275 per cent.
No. 3, sustaining $\frac{1}{2}$, 33 months.....	0.409 per cent.
No. 4, sustaining $\frac{3}{4}$, 33 months.....	0.613 per cent.

The rate of extension was nearly proportional to the times, and the total extension to the forces. M. Vicat concludes that metal thus overstrained will ultimately break, and his paper has been supposed to indicate a possibility of the ultimate failure of structures having originally an ample factor of safety.

Fairbairn made experiments of nearly the same nature as those of Vicat, upon cast-iron bars loaded transversely. These bars were 4½ feet (1.4 metres) between supports, and loaded with two-thirds their breaking weights. Cold-blast iron increased in deflection from 1.27 inches (3.23 centimetres) to 1.31 inches (3.33 centimetres) in five years; the hot-blast bars

* *Annales de Chimie et de Physique*, 1834. Tome 54, p. 35.

deflected 1.46 inches (3.7 centimetres) to 1.62 inches (4.1 centimetres) in the same time. The deflection *decreased* after 1¼ years, and increased again during the last two.

The Author has similarly investigated the action of prolonged stress, using wire of Swedish iron; but one set of samples was annealed; the other, of two sets, was left hard, as drawn from the wire blocks. The size selected was No. 36, 0.004 inch (0.01 millimetre) diameter, and were loaded with 95, 90, 85, 80, 75, 70, 65 and 60 per cent. of the breaking load as obtained by the usual method of test. The result was:

ENDURANCE OF IRON WIRE UNDER STATIC LOAD.

PER CENT. MAX. STATIC LOAD.	TIME UNDER LOAD BEFORE FRACTURE.	
	Hard wire (unannealed).	Soft wire (annealed).
95	8 days.	3 minutes.
90	35 days.	5 minutes.
85	Unbroken at end of 16 mos.	1 day.
80	91 days.	266 days.
75	Unbroken.	17 days.
70		455 days.
65		455 days.

This very remarkable difference between hard drawn and annealed iron, thus discovered by the Author, throws some light upon the discrepancy previously supposed to exist between the results of Vicat's experiments and common experience, as well as upon the conditions of safety of loaded iron structures. Soft irons and the "tin class" of metals and the woods are thus found to demand a higher factor of safety than hard iron. The elegant and valuable researches, also, of Mons. H. Tresca on the flow of solids,* and the illustrations of this action almost daily noticed by every engineer, seem to lend

* *Sur l'Ecoulement des corps solides.* Paris, 1869–72.

confirmation to the supposition of Vicat. The experimental researches of Prof. Joseph Henry, on the viscosity of materials, and which proved the possibility of the co-existence of strong cohesive forces with great fluidity,* long ago proved also the possibility of a behavior in solids, under the action of great force, analogous to that noted in more fluid substances.

On the other hand, the researches of the writer, indicating by strain diagrams that the progress of this flow is often accompanied by increasing resistance, and the corroboratory evidence furnished by all such carefully made experiments on tensile resistance as those of King and Rodman, Kirkaldy and Styffe, have made it appear extremely doubtful whether hard iron is ever weakened by a continuance of any stress not originally capable of producing incipient rupture.

Velocity of Rupture; Shock.—Kirkaldy concludes that the additional time occupied in testing certain specimens of which he determined the elongation "had no injurious effect in lessening the amount of breaking strain."† An examination of his tables shows those bars which were longest under strain to have had highest average resistance.

Wertheim supposed that greater resistance was offered to rapidly than to slowly produced rupture.

The experiments of the Author prove that, as had already been indicated by Kirkaldy, a lower resistance is offered by ordinary irons as the stress is more rapidly applied. This effect conspires with *vis viva* to produce rupture.

We conclude that the rapidity of action in cases of shock, and where materials sustain live loads, is a very important element in the determination of their resisting power, not only for the reason given already, but because the more rapidly common iron is ruptured the less is its resistance to fracture. This loss of resistance is about 15 per cent.‡ in some cases, noted by the Author, of moderately rapid distortion.

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* *Proc. Am. Phil. Society*, 1844.

† *Experiments on Wrought Iron and Steel*, pp. 62, 83.

‡ Compare Kirkaldy, p. 83, where experiments which are possibly affected by the action of *vis viva* indicate a very similar effect.

The cause of this action bears a close relation to that operating to produce the opposite phenomenon of the elevation of the elastic limit by prolonged stress, to be described, and it may probably be simply another illustration of the effect of internal strain. Metals of the "tin class" exhibit, as has been shown by the Author,* an opposite effect. Rapidly broken they offer greater resistance than to a static or slowly applied load. It has also been seen that annealed iron has, in some respects, similar qualities.

With a very slow distortion the "flow" already described occurs, and but a small amount of internal strain is produced, since, by the action noticed when left at rest, this strain relieves itself as rapidly as produced. A more rapid distortion produces internal stress more rapidly than relief can take place, and the more quickly it occurs the less thoroughly can it be relieved, and the more is the total resistance of the piece reduced. Evidence confirmatory of this explanation is found in the fact that bodies most homogeneous as to strain exhibit these effects least.

It does not now seem remarkable that, at extremely high velocities, the most ductile substances exhibit similar behavior when fractured by shock or by a suddenly applied force, to substances which are really comparatively brittle.† In the production of this effect, which has been frequently observed in the fracture of iron, although the cause has not been recognized, the inertia of the mass attacked and the actual depreciation of resisting power just observed, conspire to produce results which would seem quite inexplicable, except for the evidently great concentration of energy here referred to, which, in consequence of this conspiring of inertia and resistance, brings the total effort upon a comparatively limited portion of the material, producing the short fracture, with its granular surfaces, which is the well-known characteristic of

* *Trans. Am. Soc. C. E.*, 1874, *et seq.*

† Specimens from wrought-iron targets shattered by shock of heavy ordnance, in the possession of the Author, exhibit this change in a very unmistakable manner.

sudden rupture. Any cause acting to produce increased density, as reduction of temperature, evidently must intensify this action of suddenly applied stress.

The liability of machinery and structures to injury by shock is thus greatly increased, and it is quite uncertain what is the proper factor of safety to adopt in cases in which the shocks are very suddenly produced.

Meantime the precautions to be taken by the engineer are: To prevent the occurrence of shock as far as possible, and to use in endangered parts light and elastic members, composed of the most ductile materials available, giving them such forms and combinations as shall distribute the distortion as uniformly and as widely as possible.

The behavior of materials subjected to sudden strain is thus seen to be so considerably modified by both internal and external conditions which are themselves variable in character, that it may still prove quite difficult to obtain mathematical expressions for the laws governing them. An approximation, of sufficient accuracy for some cases which frequently arise in practice, may be obtained for the safety factor by a study and comparison of experimental results.

"Rate of Set" of Metals Subject to Stress for Considerable Periods of Time.—The results of experiments made by the Author to determine the time required to produce "set" in metals loaded more or less heavily, and to ascertain what law governs the influence of time in determining the progress and the limit of change of form as the metal yields under loads, either very small or approaching the ultimate strength of the piece, were reported to the American Society of Civil Engineers, January, 1877.*

Two methods of testing bars by transverse stress were adopted. By the first method, the bar was bent to a certain carefully measured deflection, and there held, and its effort to straighten itself was as carefully measured. This effort was at first equal to the load required to bend the bar to the observed deflection, but it gradually became less and less as

* Trans. Am. Society of Civil Engineers, 1877. *Iron Age*, 1877.

the bar took a set, and finally either became constant, or the bar broke. In the first case, this loss of straightening power ceased when the bar had taken its set completely.

By the second method, the bar was similarly mounted between supports, but was then loaded with a "dead load" of a certain carefully measured amount, and the manner in which deflection took place and its amount, were very accurately observed. When the deflection no longer increased, and the bar remained at a constant deflection, the set was complete. In some cases the increase of deflection did not cease until the bar broke.

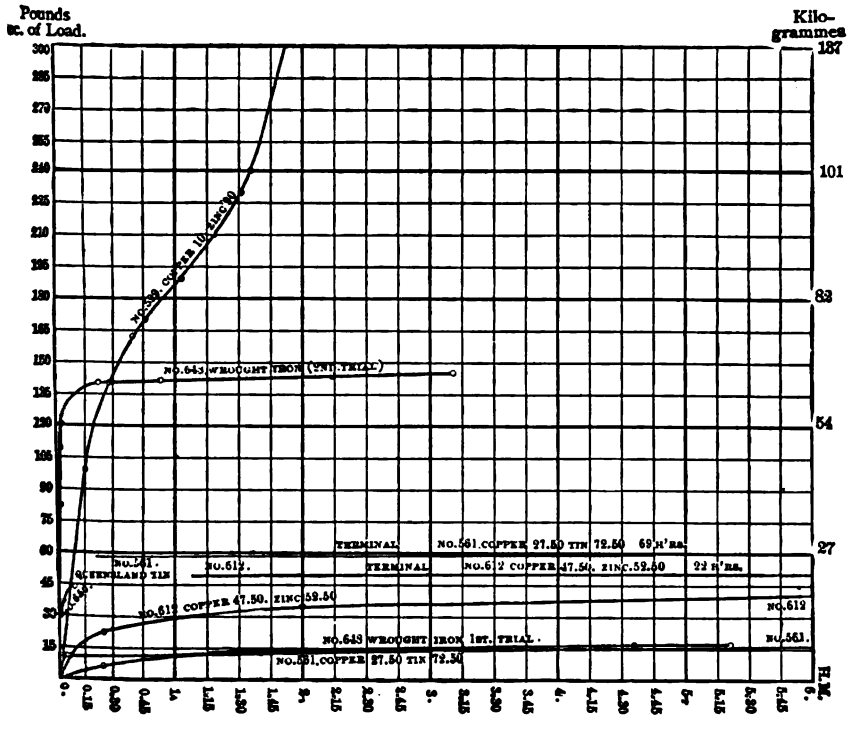

FIG. 106.—DECREASE OF RESISTANCE WITH TIME.

This research was thus divided into two parts: The first on the observed decrease of resistance at a fixed distortion; the

second on the observed increase of deflection under static loads. We here present the principal deductions.

Bars were prepared of square section, 1 inch (2.54 centimetres) in breadth and depth, and 22 inches (56 centimetres) in length between bearings. They were flexed in a machine for testing the resistance of materials to transverse stress, and the load and deflection carefully measured. As the bars were retained at a constant deflection, their effort to resume their original form gradually decreased, and the amount of this effort was from time to time noted. When this effort or resistance had become considerably decreased, the bar was released and the set measured. This operation was repeated with each until the law of decrease of elastic resistance was detected. Curves (Fig. 106) were constructed, illustrating graphically this law.

In all of these metals the set and the loss of effort to resume the original form were phenomena requiring time for their progress, and in all, except in the case of No. 599—which was loaded heavily—the change gradually became less and less rapid, tending constantly toward a maximum.

So far as the observation of the Author has extended, the latter is always the case under light loads. As heavier loads are added, and the maximum resistance of the material is approached, the change continues to progress longer, and, as in the case of the brass above described, it may progress so far as to produce rupture, when the load becomes heavy, if the metal does not belong to the "iron class." The brass broke under a stress 25 per cent. less than it had sustained previously.

Other experiments were conducted with the same object as those above described. In these experiments, however, the load, instead of the distortion, was made constant, and deflection was allowed to progress, its rate being observed, until the test piece either broke under the load or rapidly yielded, or until a permanent set was produced. The results of these experiments are in striking accordance with those conducted in the manner previously described; they exhibit the fact of a gradually changing rate of set for the several cases of light or heavy loads, and illustrate the distinctions between

the two classes of metal equally well. In one case, a "time-test" was made when the deflection was 0.546 inch and the load 1,233 pounds. The result noted was singular. The effort steadily decreased at a varying rate, which is indicated by the diagram of time and loads, and the bar finally snapped sharply, and the two halves fell upon the floor. The effort had decreased to 911 pounds. The deflection was precisely what it had been under the load of 1,233 pounds. The beam had balanced at 911 pounds for about three minutes when the fracture took place.

The bar was hard, brittle, and elastic, but must apparently be classed with tin in its behavior under either continued or intermitted stress.

There seems to the Author to exist a distinction, illustrated in these cases, between that "flow" which is seen in these metals, and that to which has been attributed the relief of internal stress and the elevation of the elastic limit by strain and with time.

This last phenomenon—the exaltation of the elastic limit by strain—has been observed very strikingly, by the writer, in the deflection of iron bars by transverse stress. The plate exhibits also the strain diagrams obtained by transverse deflection of four bars of ordinary merchant wrought iron, which were all cut from the same rod. Of these, two were tested in the Fairbanks machine, in which the deflection remains constant when the machine is untouched, while the load gradually decreases—or, more properly, while the effort of the bar to regain its original form, decreases. The other two were tested by dead loads—the load remaining constant, while the deflection may vary when the apparatus is left to itself.

These two pairs of specimens were broken; one in each set by adding weight steadily until the end of the test, so as to give as little time for elevation of elastic limits as was possible, and one in each set by intermittent stress, observing sets, and the elevation of the elastic limit of metals. As seen by study of these diagrams, both classes, when strained by flexure, gradually exhibit less and less effort to restore themselves to their original form.

In the case of the tin class, this loss of straightening power seems often to continue indefinitely, and, as in one example here illustrated, even until fracture occurs.

With iron and the class of which that metal is typical, this reduction of effort becomes gradually less and less rapid, and finally reaches a limit after attaining which the bar is found to have become strengthened, and the elastic limit to have become elevated. In this respect the two classes are affected by time of stress in precisely opposite ways.

The plate exhibits superior ultimate resistance of bars which have been intermittently strained, as well as elevation of the elastic limit. The parallelism of the "elasticity lines" obtained in taking sets, shows that the modulus of elasticity is unaffected by the causes of elevation of the elastic limit.

Evidence appealing directly to the senses has been presented in the course of experiment on the second class of metals, of intra-molecular flow. When a bar of tin is bent, it emits while bending the peculiar crackling sound, familiarly known as the "cry of tin." This sound has not been observed hitherto, so far as the Author is aware, when a bar has been held flexed and perfectly still. In several cases in experiments on flexure of metals of the second class, bars held at a constant deflection have emitted such sounds hour after hour, while taking set and losing their power of restoration of shape.*

The Variation of the Normal Elastic Limits with Time.—The elevation of the normal series of elastic limits, and of strength, by intermitting strain was discovered by the Author and by Captain Beardslee, of the U. S. Navy, independently, in the year 1873. It is variable in amount with different materials of the iron class, and the rate at which this exaltation progresses is also variable. With the same material and under the same conditions of manufacture and of subsequent treatment, the rate of exaltation is quite definite, and may be expressed by a very simple formula. The process of exaltation of the normal elastic limit due to any given degree of strain usually nearly approaches a maxi-

* *Trans. Am. Soc. C. E.*, 1876.

mum in the course of a few days of rest after strain, its progress being rapid at first and the rate of increase quickly diminishing with time. For some good bridge or machinery irons, the amount of the excess of the exalted limit, as shown by subsequent test, above the stress at which the load had been previously removed may be expressed approximately by the formula :

$$E' = 5 \log T + 1.50 \text{ per cent.};$$

in which the time, T, is given in hours of rest after removal of the tensile stress which produced the noted stretch.

Captain Beardslee found that, with good ductile iron, the ultimate strength is increased over 15 per cent. by being strained nearly to its limit of tenacity and then allowed to rest for at least one day. With coarse brittle iron, the increase of strength is not so great, a number of specimens of this character showing an average gain of about 6 per cent. Another set of experiments upon the action of this law was made by breaking a bar in its normal condition, and again, several days afterward, breaking one of the pieces. The second piece invariably showed a very much greater strength than the first, the gain in some cases being 20,000 pounds per square inch, or nearly 40 per cent.

This peculiar effect is well shown by a pair of bars exhibited in Fig. 107.

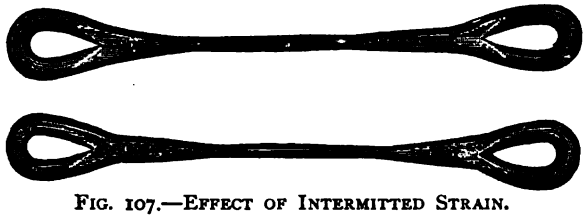

FIG. 107.—EFFECT OF INTERMITTED STRAIN.

The upper specimen broke in the eye while under test and after it had begun to draw down, as seen near the letter T in the name at the right. When repaired and again tested next day, it broke in a new place nearer the middle.

The extent of this elevation of the normal series of elastic limits by intermitted stress is affected by quality, thus:

EFFECT OF REST UPON IRONS.

Test pieces rested 18 *hours.*

NUMBER AND MARKS.	ULTIMATE STRENGTH.		GAIN IN STRENGTH.		REMARKS.	
	First stress.	Second stress.	Pounds.	Per cent.		
	Lbs.	*Lbs.*				
62 boiler iron	48,600	56,500	7,900	16.0	Not broken	
63	49,800	57,000	7,200	16.4	Broken	Average, 15.8 per cent.
64	49,800	58,000	9,200	18.4	Broken	
65	48,100	54,400	6,300	13.1	Broken	
66	48,150	55,550	7,400	15.0	Broken	
67 contract chain	50,200	54,000	3,800	7.5	Broken	Average, 6.4 per cent.
68	50,250	53,200	2,950	5.8	Not broken	
69	50,700	55,300	4,600	9.0	Not broken	
70	49,600	52,900	3,300	6.6	Not broken	
71	51,200	52,800	1,600	3.2	Not broken	
72 iron K	58,800	64,500	5,700	9.6	Broken	Average, 9.4 per cent.
73	59,000	65,800	6,800	11.5	Broken	
74	56,400	60,600	4,200	7.3	Broken	

These experiments indicate that a structure composed of iron of low ductility will receive comparatively slight benefit from the operation of this law, while ductile, fibrous metal, which possesses greater power to resist sudden strains, although less capable of resisting steady stress, gains in this latter power to a greater extent by the effect of strains already successfully borne.

Evidence of Overstrain.—Thus a piece once overstrained, carries, permanently, unmistakable evidence of the fact, and can be made to reveal the amount of such overstrain at any later time with a fair degree of accuracy. This evidence cannot be entirely destroyed, even by a moderate

degree of annealing. Often, only annealing from a high heat, or reheating and reworking can remove it absolutely. Thus, too, a structure, broken down by overstrain, retains in every piece a register of the maximum load to which that piece has been subjected; and the strain-sheet of the structure, as strained at the instant of breaking down, can be laid down.

Here may be found a means of tracing the overstrains which have resulted in the destruction or the injury of any iron or steel structure, and of ascertaining the cause and the method of its failure, in cases frequently happening, in which they are indeterminable by any of the usual methods of investigation.

In illustration of an application of facts known to the determination of the causes and the method of the injury or the destruction of a structure, assume a bridge to have been built with a span of 150 feet, and to have been given such proportions that, with a weight of 1,200 pounds per running foot, and a load of one ton per running foot, the maximum stress on end rods, or other members most strained, is as high as 20,000 pounds per square inch of section of metal. Suppose this bridge to have its tension members composed of a fair, but unrefined, iron, having an elastic limit at about 17,000 pounds per inch (1,195 kilogrammes per square centimetre), and a tenacity of 45,000 to 48,000 pounds (3,164 to 3,374 kilogrammes per square centimetre), and with an extensibility of about 20 per cent.

Suppose this structure to break down under a load exceeding that usually sustained in ordinary work and portions of the several tension members to be subsequently removed, and, a few days after the accident, to be carefully tested, with the results shown on page 524.

The extensibility is found to be as little as from ten to fifteen per cent.

The tension members are straight bolts without upset ends, the threads being cut, as was formerly common, in such a manner that the section at the bottom of the thread is one-third less than the sectional area of the body of the bar. The location of the tested pieces in the structure being

noted, it is found that the stronger metal, having also the highest elastic limit, came from the neighborhood of the point at which the bridge gave way, and that the weakest metal, and that exhibiting the lowest elastic limit, came usually from points more or less remote from the break. It is not likely that in all cases the increase in the altitude of the elastic limit, and the increase noted in the ultimate strength of the samples would exhibit a regular order coincident with the order of the rods as to position in the structure; since the magnitude and the arrangement of the bars would, to a certain extent, determine the relative amounts of strain thrown upon them by overloading any one part of the truss. For present purposes, we may assume the order of arrangement to be thus coincident.

	ELASTIC LIMIT.		TENACITY.	
	British.	Metric.	British.	Metric.
Sample No. 1	16,500	1,160	46,000	3,243
" " 2	18,000	1,265	48,000	3,374
" " 3	20,000	1,406	48,000	3,374
" " 4	22,500	1,582	50,000	3,515
" " 5	25,000	1,758	52,000	3,656
" " 6	27,500	1,933	52,000	3,656
" " 7	28,000	1,968	52,000	3,656
" " 8	30,000	2,109	52,000	3,656
" " 9	32,000	2,250	53,000	3,726
" " 10	34,000	2,390	53,000	3,726

On examination of the figures as above given, the engineer would conclude: First, that the original apparent elastic limit of the iron used in this case must have been not far from 17,000 pounds per square inch, and that its tenacity was between 46,000 and 48,000 pounds; secondly, that this primitive elastic limit had been elevated, by subsequent loads exceeding that amount, to the higher figures given by the bars numbered from 3 to 10 inclusive; thirdly, that the ultimate strength of the material had been, in some examples given above, increased by similarly intermitted strain.

It would be concluded that the ordinary loads, such as had been carried previously to the entrance upon the bridge of that which caused its destruction, never exceeded, in their straining action, 16,500 pounds per square inch of section of tension rod at the part of the truss from which No. 1 had been taken, and that the other rods tested had carried, probably, at the time of the accident, loads approximately equal to those required to strain them to the extent measured by their elastic limits at the time of testing them.

It would be concluded that the rod from which No. 10 was cut was either that most strained by the load, and therefore nearest the point of fracture of the truss, or that it was very near that point, and it would be made the basis of comparison in further studying the case.

As this elastic limit approaches most nearly the breaking strength of the metal, we may apply the formula for the elevation of the elastic limit with time after intermitted strain, which has been above given as derived from tests of a metal of very similar quality. Taking the time of intermission as one week, the extent of the increase has a probable value not far from $E' = 5 \log. 168 + 1.5 =$ nearly $12\frac{1}{2}$ per cent. The magnitude of the stress upon this piece at the time of the accident was therefore 34,000, less one-ninth of that value, or about 30,000 pounds per square inch of cross section of the bar. This corresponds to about 45,000 pounds per square inch at the bottom of the thread, and is within 5 per cent. of the primitive breaking strength of the iron. The bar, if broken at the screwed portion, has therefore yielded under a dead load which was at least equal to its maximum resistance, or under a smaller load acting so suddenly as to have the effect of a real "live load." Or, the slight difference here noted may be due to a flaw at the point of fracture. However that may be, it is almost certain that the body of the rod has sustained a stress of not far from 30,000 pounds per square inch.

But it is found, on further investigation, that the load on the structure at the time of the accident was but sufficient to make the maximum stress on these rods—if properly distrib-

uted—20,000 pounds per square inch (1,406 kilogrammes per square centimetre) at the threaded part of the piece, which piece, it has been seen, has been broken by a strain nearly double that figure. The fact is at once inferable that the load came upon these members with such suddenness as to have at least the effect of a live load, and giving a maximum stress equal to twice that produced by the same load gradually applied, *i. e.*, the case in which the load falls through a height equal to the extension of the piece strained by it, the resistances being assumed to increase directly as the extension up to the point of rupture—an assumption which is approximately correct for brittle materials like hard cast iron, but quite erroneous in the case of some ductile materials, which latter sometimes give a "work of ultimate resistance" amounting to three-fourths or even five-sixths of the product of maximum resistance by the extension.

This accident was therefore caused by the entrance upon the bridge of a load capable of straining the metal to about one half of its ultimate strength, if slowly applied, but which, in consequence of its sudden application, doubled that stress. This sudden action may have been a consequence either of its coming upon the structure at a very high speed, or a result of the loosening of a nut, or of the breaking of a part of either the bridge floor or of one of the trucks of the train. The latter occurrence, permitting the load to fall even a very small distance, would be sufficient.

Effect of Orthogonal Strains.—In whatever direction the stress may be applied, and whatever the line of strain, the effect is the same so far as it concerns the normal elastic limit.

Iron and steel wires broken by tension are found to have the transverse elastic limit abnormally elevated, and to have become very stiff and of comparatively slight ductility. This is true of wires of some other metals, and of heavier sections of metal. A large quantity of cold-rolled shafting of all sizes, of which both the longitudinal and the transverse dimensions had been altered by rolling cold, when tested by the Author exhibited great increase of stiffness and strength, and

an even more considerable exaltation of the normal elastic limit. Torsion similarly stiffened wires and rods longitudinally, and test pieces longitudinally strained become stiffer against torsionally and transversely applied stress. Thus orthogonal strains mutually affect orthogonal resistances of metals; and the engineer is, by this fact, compelled to study these mutual influences in designing structures in which the stresses approach or exceed, separately or in combination, the normal *primitive* elastic limit of his material.

The following is, in detail, an account of the behavior of a bar of "good merchant iron" under the action of intermittent and successively applied orthogonal strain (transverse succeeded by tension):*

A bar of good bridge or cable iron 2 inches (5.08 centimetres) square and about 4 feet (1.2 metres) long was split longitudinally; one half was cut into tension test pieces, and the other half bent on the transverse testing machine to an angle at the middle of about 120°; the bent bar was then cut into tension test pieces like the first, and finally all these pieces were broken in tension. On examining the results thus obtained, it was found that the original elastic limit of the metal, as exhibited by the test of the unbent bar, had been exalted by transverse strain in all parts of the bar which had been so strained before being tested by tension. This elevation of the primitive normal limit had not occurred, as would have been expected, to the greatest extent at the points most strained, *i. e.*, nearest the bend at the middle of the strained bar and less and less as the point of maximum strain was departed from, until, at the ends of the bar, this elevation became much less observable, but took place irregularly, and, on the average, about as much at one part as at another.

The elevation of the primitive elastic limit, in this instance, is 30 per cent. as an average, and in some parts of the bar about 50 per cent. The new series of the elastic limits are less uniform in value than in the original bar.

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* *Trans. Am. Society C. E.* Vol. IX., No. cxci., 1880.

CHAPTER XVII.

CONDITIONS AFFECTING STRENGTH OF NON-FERROUS METALS AND ALLOYS.

The Conditions Affecting the Strength of the Non-Ferrous Metals are precisely such as have been found to modify the valuable properties of iron and steel, and of other materials of construction used by the engineer. The effect of every change, whether chemical or physical, of internal or of external conditions, affecting the metal is seen in a modification of its strength, elasticity, ductility and resilience. Change of temperature, either gradual or sudden, alteration of methods of manufacture, differences, however slight, of composition and of density, and every variation of the magnitude, and of the number of applications, of the load has an effect, more or less marked and important, upon the value and reliability of the metal as a structural material.

The effect of heat and of variation of temperature upon the non-ferrous metals and upon the alloys has been but little studied; but some important facts have become well ascertained.

The Strength of Copper is modified by temperature in the same general way as iron (Part II., Mat. of Eng.). It is reduced steadily, and according to a simple law, as temperature rises, finally becoming zero at the point of fusion. Decrease of temperature causes increase of strength.

A committee of the Franklin Institute, of the State of Pennsylvania, consisting of Professor W. R. Johnson, Benjamin Reeves, and Professor A. D. Bache, were engaged, during a period extending from April, 1832, to January, 1837, in experiments upon the tenacity of iron and of copper, under the varying conditions of ordinary use.

The effect of change of temperature upon those metals was investigated with equal intelligence and thoroughness, and most valuable results were obtained.

Upward of one hundred experiments upon copper, at temperatures ranging from the freezing point up to 1,000° Fahrenheit, exhibited plainly the fact that a gradual diminution of strength occurs with increase of temperature, and *vice versa*, and that the change is as uniform as the unavoidable irregularities in the structure of the metal would allow.

The law of this variation of tenacity, within the limits between which the experiments were made, was found to be closely represented by the formula,

$$D^2 = C\,T^3,$$

i. e., the squares of the diminutions of tenacity vary as the cubes of the observed temperatures measured from the freezing point.

The following are the tenacities of copper at various temperatures, as determined by experiment, to the nearest round numbers:

TENACITIES OF COPPER WITH VARYING TEMPERATURES.

TEMPERATURE.		TENACITY.		TEMPERATURE.		TENACITY.	
F.	C.	Lbs. per sq. in.	Kilogs. per sq. cm.	F.	C.	Lbs. per sq. in.	Kilogs. per sq. cm.
122°	50°	33,000	231	602°	316°	22,000	...
212	100	32,000	225	801	427	19,000	144
302	150	31,000	218	912	490	15,000	105
482	250	27,000	190	1.016	546	11,000	77
545	290	25,000	176	2,032	1,111	0	0

The Effect of Heat on Bronze and the kalchoid alloys of copper, tin and zinc was determined by the British Admiralty at Portsmouth in the year 1877.*

* London Engineering, Oct. 5, 1877.

The metal was cast in the form of rods one inch in diameter, and composed of five different alloys as follows:

No. 1. Copper, 87.75 ; tin, 9.75 ; zinc, 2.5.
No. 2. Copper, 91 ; tin, 7 ; zinc, 2.
No. 3. Copper, 85 ; tin, 5 ; zinc, 10.
No. 4. Copper, 83 ; tin, 2 ; zinc, 15.
No. 5. Copper, 92.5 ; tin, 5 ; zinc, 2.5.

The specimens were heated in an oil bath near the testing machine, and the operation of fixing and breaking was rapidly and carefully performed, so as to prevent, as far as possible, loss of heat by radiation. The strength and ductility of the above test-pieces, at atmospheric temperature, were as follows: No. 1, 535 pounds, 12.5 per cent.; No. 2, 825 pounds, 16 per cent.; No. 3, 525 pounds, 21 per cent.; No. 4, 485 pounds, 26 per cent. and No. 5, 560 pounds, 20 per cent. As the heat increases a gradual loss in strength and ductility occurs, up to a certain temperature, at which, within a few degrees, a great change takes place, the strength falls to about one half the original, and the ductility is wholly gone. Thus in alloy No. 1, at 400° F. (204° C.) the tensile strength had fallen to 245 lbs., and the ductility to 0.75 per cent.; the precise temperature at which the change took place was ascertained to be about 370° F. (188° C.). At 350° F. (177° C.), the tensile strength was 450 lbs., and ductility 8.25 per cent. At temperatures above the point where this change begins and up to 500° F. (260° C.) there is little if any loss of strength.

Phosphor-bronze was less affected by heat, and at 500° F. (260° C.) retained two-thirds its tenacity and one-third its ductility. Muntz metal (copper, 62; zinc, 38) was found reliable up to the limit, and iron and steel were not injured.

The following table exhibits the results of these experiments in convenient shape.

THE EFFECT OF HEAT ON TENACITY OF KALCHOID ALLOYS.

TEMPERATURE.		GUN-METAL RODS 1 INCH DIAMETER.												PHOSPHOR-BRONZE RODS 1 INCH DIAMETER.		MUNTZ-METAL RODS .74 INCH DIAMETER.	
		1. Copper ....87.75 Tin..... 9.75 Zinc 2.50		2. SECOND SET. Copper ....87.75 Tin..... 9.75 Zinc 2.50		3. Copper ..... 91 Tin..... 7 Zinc 2		4. Copper ..... 85 Tin..... 5 Zinc 10		5. Copper ..... 83 Tin..... 2 Zinc 15		6. Copper .....92.5 Tin..... 5 Zinc 2.5		Copper.... 92.5 Tin..... 7 Zinc..... .5		Copper ..... 62 Zinc..... 38	
		Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.
Cent.	*Fahr.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*	*Lbs.*	*Per ct.*
	Atmos-pheric.	535	12.5	575	8.75	525	16.	525	21.	485	26.	560	20.	609	17.5	700	2.5
37.7°	100°	505	10.	....	....	525	15.5	550	18.	480	26.	....	....	614	17.	680	2.5
65.5	150	525	11.	....	....	525	14.	530	19.5	450	25.5	....	....	610	18.	720	3.9
93.3	200	485	10.	535	8.75	460	9.	523	19.	460	26.25	440	11.	605	18.	685	3.9
121.1	250	505	10.	385	5.	255	3.	515	16.	440	26.	360	6.	580	15.	670	5.
148.9	300	500	10.	295	.66	265	nil.	531	18.25	435	23.	255	.66	575	12.	650	2.5
176.7	350	450	8.25	295	nil.	....	....	495	17.	435	25.	....	....	470	7.	650	2.25
210.0	400	245	.75	....	....	260	nil.	260	2.	435	25.	....	....	424	5.	600	2.25
232.2	450	265	nil.	....	....	....	....	250	2.	152	1.2	....	....	380	4.	615	3.75
260.0	500	250	nil.	....	....	275	nil.	230	2.	152	nil.	....	....	420	5.	620	5.

Various Metals.—Variations of temperature, according to Baudrimont,* produce alterations of the tenacity of metals, as below. The metals were in the form of wire, nearly 0.4 millimetre (0.0158 inch) in diameter, except the iron, which was 0.175 mm. (0.0067 inch), and the copper, 0.48 mm. (0.0189 inch). The tenacity is reduced to kilogrammes per square centimetre. All, except iron, are weakened by increase of temperature.

TENACITIES OF METALS AT VARYING TEMPERATURES.

	TENACITY IN KILOGS. PER SQ. CM.		
	0° C. (32° F.)	100° C. (212° F.)	200° C. (392° F.)
Gold	1,840	1,522	1,288
Platinum	2,263	1,928	1,728
Copper	2,510	2,187	1,822
Silver	2,832	2,327	1,858
Palladium	3,648	3,248	2,708
Iron	20,540	19,173	21,027

The Modulus of Elasticity of hard-drawn iron, copper, and brass wires was found by Loomis and Kohlrausch† to vary with temperature according to a law expressed by the equation

$$E = E_0(1 - at - bt^2),$$

in which E is the modulus at the temperature t, E_0 that at 0° and a and b experimentally determined co-efficients; for the Centigrade scale, their values are

	a	b
Iron	0.000 483	0.000 000 12
Copper	0.000 572	0.000 000 28
Brass	0.000 485	0.000 001 36

* Annales de Chimie et de Physique, 1850.

† Am. Jour. Science and Arts, vol. l., Nov., 1870.

Thus, the reduction of the value of the modulus between the melting point of ice and the boiling point of water is, for iron 4.6 to 5 per cent.; for copper, 5.5 to 6 per cent.; for brass, 5.6 to 6.2 per cent., and this variation is most rapid at the highest temperature. The values of the moduli were found to be very closely proportional to the co-efficients of expansion.

The following determinations were made by Wertheim:

VARIATION OF MODULI OF ELASTICITY WITH TEMPERATURE.

	S. G.	15° C., 59° F.		100° C., 212° F.		200° C., 392° F.	
		Metric.	British.	Metric.	British.	Metric.	British.
Lead	11.232	173	2.4	163	2.3	....	....
Gold	18.035	558	7.9	531	7.6	548	7.9
Silver	10.304	715	10.2	727	10.4	637	9.1
Palladium	11.225	979	14.0	....	....	....	...
Copper	8.936	1,052	15.0	983	14.0	786	11.2
Platinum	21.083	1,552	22.2	1,418	20.3	1,296	18.5
Steel (wire)	7.622	1,728	24.9	2,129	30.4	1,928	27.5
Steel (cast)	7.919	1,956	26.5	1,901	27.1	1,792	25.6
Iron	7.757	2,079	26.8	2,188	31.2	1,770	25.2

The metric values are in thousands of kilogrammes per square centimetre; the British in millions of pounds per square inch.

The Stress produced by Change of Temperature is easily calculated when the modulus of elasticity and the coefficient of expansion are known, thus:

Let E = the modulus of elasticity;
λ = the change of length per degree and per unit of length;
$\Delta t°$ = the difference of initial and final temperatures;
p = the stress produced.

Then:

$$p : E :: \lambda\ \Delta t^\circ : 1,$$

$$\therefore p = \lambda E\ \Delta t^\circ$$

For good wrought iron and steel, taking E as 28,000,000 pounds on the square inch, or 2,000,000 kilogrammes on the square centimetre, and λ as 0. 0000068 for Fahrenheit, and as 0.0000120 for Centigrade degrees:

$$\left.\begin{aligned} p &= 190\ \Delta t^\circ \text{ Fahr., nearly} \\ &= 25\ \Delta t^\circ \text{ Cent., nearly} \end{aligned}\right\}$$

For cast iron, taking $E = 16.000{,}000$; $\lambda = 0.0000062$:

$$\left.\begin{aligned} p &= 100\ \Delta t^\circ \text{ Fahr., nearly} \\ &= 12\ \Delta t^\circ \text{ Cent., nearly} \end{aligned}\right\}$$

This force must be allowed for as if a part of the tension, T, or compression, C, produced by the working load when the parts are not free to expand.

Sudden Variation of Temperature has an effect, very usually, upon the non-ferrous metals, which is afterward seen in a permanent alteration of their properties. Repeated heating and cooling causes a permanent change of form, and sudden cooling from high temperatures causes a modification of the tenacity and ductility of the kalchoids and the metals composing such alloys, which is precisely the opposite of that produced on steel. Thus copper, brass, and bronze, suddenly cooled from a low red heat, are softened and weakened and greatly improved in malleability and ductility. This process, which is one of hardening and tempering with steels, is thus one of softening with other metals. On the other hand, very slow cooling softens or "anneals" steels, while it hardens the non-ferrous metals and alloys. Thus, also, casting bronze ordnance or other castings in chills increases the value of the metal by preventing liquation and securing homogeneousness and maximum density.

The Effect of Chill-casting is exhibited in the following tables of tests by tension furnished to the Author by the U. S. N. Department in the course of a series of investigations in 1877. The metal has the composition, copper (Lake Superior), 9; tin, 1; it was cast either in chills or in sand as specified, after having been melted in a reverberatory furnace, the copper first and the tin three hours later. The specimens tested were of the "short" pattern, and the reduction of section, rather than the elongation recorded, is the measure of relative ductility. The tables also exhibit the method of testing usual in the Ordnance Department of the U. S. Navy in 1875–6. British measures are here used.

EFFECT OF CASTING BRONZE IN "CHILLS."

Navy Ordnance-Bronze.

MARK.	TENSILE STRENGTH PER SQUARE INCH OF—		PERMANENT ELONGATION IN PARTS OF ORIGINAL LENGTH.	PERMANENT REDUCTION OF AREA IN PARTS OF ORIGINAL.	SPECIFIC GRAVITY.	
	Original section.	Fractured section.				
M 1, 3-4-75.....	42,037	70,000	.4795	.40	.....	
M 2, 3-4-75.....	41,768	71,600	.478	.417	.....	
BB IX.....	22,385	.....	.100	....	.....	Full of large tin spots.
M 2, 5-6-75.....	45,737	.....	.522	.470	.....	
No. 3, 8-21-75..	49,772	65,600	.2603	.240	8.878	Cast in chill mould.
No. 2, 8-21-75..	48,000	60,000	.211	.20	.....	Cast in chill mould.
GB 2, 5-6-75 ...	35,820	.....	.4075	.50	.....	
GB 3, 5-6-75 ...	29,818	.....	.0291	....	8.392	Flaw in the breaking portion.
B 3 L, 12-70-75..	33,630	39,000	.135	.134	.....	Cast in chill mould.
M 1 C, 3-11-76..	51,459	91,600	.580	.438	.....	
B 2 C, 3-11-76..	45,837	73,450	.336	.376	.....	Cast in chill mould.
B 3 C, 3-11-76..	44,869	71,600	.415	.373	8.853	Cast in chill mould.

The guns cast in chill moulds were composed of 10 parts of copper to 1 part of tin; the others were of 9 parts of copper to 1 part of tin.

In the course of experiments made by Major Wade,* three

* Report on Ordnance.

howitzers, Nos. 27, 28, and 29, were cast from the same liquid metal. No. 27 was cast when the metal was at the highest temperature, No. 28 was cast fifteen minutes later, and No. 29 fourteen minutes after No. 28. The following results were obtained:

NUMBER.	TIME OF METAL IN LADLE, MINUTES.	TEMPERATURE OF METAL AT CASTING.	SPECIFIC GRAVITY—				TENACITY—		
			Of gun-heads.	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
					Gun mould.	Separate mould.		Gun mould.	Separate mould.
27	0	Highest ...	7.986	8.195	8.686	8.554	17,761	50,973	31,132
28	15	Mean.....	8.351	8.551	8.823	8.447	28,995	52,330	28,153
29	29	Lowest	8.538	8.752	8.816	8.376	23,722	56,786	28,082

In casting another howitzer, No. 30, small test-bars were cast in separate moulds, one of which was of cast iron, to ascertain the effect of sudden cooling, and the others were of clay, similar to the gun-mould. The tests of all the samples from this casting were as follows:

	SPECIFIC GRAVITY.	TENACITY.
Small bars cast separately in iron mould..	8.953	37,688
Small bars cast separately in clay mould..	8.313	25,783
Small bar cast in gun mould	8.896	53,798
Gun-head samples	8.490	35,578
Finished howitzer	8.733	

The effect of the chill is evidently very beneficial, and iron moulds should, therefore, always be used where possible in the casting of bronze; with brass they are less necessary.

Effect of Tempering and Annealing.—Riche determined the effect of tempering and annealing upon the

density of the bronzes, finding that tempering increased the density of those rich in tin but not of others, as gun-bronzes; and that annealing reduces the density of tempered bronze although it does not entirely destroy that effect. Density is increased to a considerable degree by mechanical action as well as by tempering.

Successive temperings and annealings produce, on the whole, an increase of density. Tempering, according to both Darcet and Riche, softens the bronzes rich in tin, *i.e.*, those containing about 20 per cent. tin. Thus, Riche obtained the result that such bronzes, tempered, can be moulded in the press, while they will crack if untempered or annealed. Bronze and steel exhibit opposite behavior in this respect. The same author finds that working hot does not increase the density more than working at low temperature. The metal increases in density very rapidly by working hot, and without danger of rupture; while cold the action is extremely slight and very difficult.

There is evidence that the method of making gongs by the Chinese involves working hot under the hammer.*

Riche, reaches the following conclusions:†

"The bronzes rich in tin (18 to 22 per cent.) increase in density with tempering; and annealing lessens the density of tempered bronze, but in a less proportion. The density is considerably increased by the alternate action of tempering and annealing, and of the press. These effects, the reverse of those in steel, coincide with the fact that tempering softens bronze while it hardens steel.

"This softening, discovered by Darcet, is not sufficient to allow of this bronze being worked cold for industrial purposes. It was shown that this metal—extremely hard when cold and pulverizable at red heat—is forged and rolled at dark red heat with remarkable facility. This fact enabled me, in common with M. Champion, to succeed in the manufacture of tamtams, and other sonorous instruments, by the method followed in the East.

* Industries Anciennes, etc. Lacroix, Paris, 1869.

† Annales de Chimie et de Physique, vol. xxx., 1873.

"Tempering produced no apparent softening in the bronzes less rich in tin (12 to 6 per cent.); and if they are tempered for industrial uses it is more especially in order to detach the oxide produced during the reheating of the matter in the course of the operations.

"It was found that in the axis of a cannon, and especially toward the muzzle, there are some parts very rich in tin and in zinc.

"The density of copper, subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the reheating; while in the first case the mechanical action increases the density, in the second mechanical action diminishes the density.

"Mechanical action increases the density of yellow brass, and this effect is counteracted in part by tempering, and especially by annealing. It is thought that annealing is preferable to tempering in working with brass.

"Mechanical action, tempering, and annealing, do not sensibly change the volume of similor and of the bronzes of aluminium, alloys remarkable for the facility with which they can be worked.

"While repeated mechanical action increases the density of the bronzes rich in tin, especially of porous copper, of copper alloyed with iron, of brass, it evidently diminishes the density of copper exposed to the air during reheating, and it produces no noticeable alteration in the volume of similor or of aluminium bronze. Tempering produces on brass, and especially on the bronzes rich in tin previously annealed, an increase in density, contrary to what takes place in steel, copper and glass.

"It will be perceived that tempering diminishes the density of a body, because the surface, cooled before the centre, cannot contract freely by reason of the resistance that the interior parts dilated at this moment offer to contraction."

Copper and its alloys should not be exposed to the air while heated, since it is certain to oxidize.

The singular avidity with which copper and the alloys absorb oxygen, causes great variation of their strengths.

The Effect of Time, and Velocity of Rupture, on the action of stress is not less important with the non-ferrous than with the ferrous metals. A very important difference is found to exist between the two classes. (See Part II., Art. 295, M. of E.) The rupture of the non-ferrous metals takes place under lower stresses, as the time of operation is greater, and the fracture is more slowly produced. The contrary is the case with iron and steel. With non-ferrous metals, the piece strained may give way, ultimately, under static loads greatly less than those required to produce immediate rupture. This occurs to a less extent with soft annealed iron, and still less with harder irons and steels. Cast iron is stated by Hodgkinson to be capable of sustaining, indefinitely, loads closely approaching the breaking load under test. Some of the alloys will probably exhibit similar differences.

With rapid distortion, the resistance is increased with non-ferrous metals, decreased with iron.

The Author has, therefore, enunciated a principle which had been deduced from experiments on wrought iron, which is, evidently, of vital importance to the engineer, viz.: "That the time during which applied stress acts is an important element in determining its effects, not only as an element which modifies the effect of the *vis viva* of the attacking mass and the action of the inertia of the piece attacked, but also as modifying seriously the conditions of production and relief of internal strain by even simple stresses." *

Should it be true, as suggested by the Author, that the cause of the variation of resistance, sometimes observed with increased velocity of distortion, is closely related to the cause of the variation of the elastic limit by strain,† it would seem to be a corollary that materials so inelastic and so viscous as to be incapable of becoming internally strained during distortion, should offer greater resistance to rapid than to

* Trans. American Society of Civil Engineers, vol. iv., p. 334.

† See Part II., Mat. of Eng.; figures 135–138.

slowly-produced distortion, in consequence of their inability to "flow" so rapidly as to reduce resistance by such fluxion at the higher speed, or by correspondingly reducing the fractured section. This principle has been shown, by a large number of experiments, to be frequently, if not invariably, the fact. Copper, tin, and other inelastic and ductile metals and alloys, were found by the author to exhibit this behavior, and are therefore quite opposite in this respect to commercial wrought iron and worked steel.

The records of the Mechanical Laboratory of the Stevens Institute of Technology frequently illustrate the proposition that metals which gradually yield under a constant load offer increased resistance with increased rapidity of rupture.

The curves of deflections of a considerable number of ductile metals and alloys are very smooth when the time during which each load has been left upon them is the same; but whenever that time has been variable the curve has been irregular. Bars of such metals broken by transverse stress give a greater resistance to rapidly increasing stress than to stress slowly intensified. Two pieces of tin, as described in pp. 542–544, were broken by tension, the one rapidly and the other slowly. The first broke under a load of 2,100 and the latter of 1,400 pounds. The example illustrates well the very great difference which is possible in such cases, and seems to the writer to indicate the possibility, in extreme cases, of obtaining results which may be fatally deceptive when the time of rupture is not noted.

The depression of the elastic limit has been observed previously in materials, but less attention has been paid to it than the importance of the phenomenon would seem to demand.

The strain diagram of a bronze bar is nearly hyperbolic; but the law of Hooke, *ut tensio sic vis*, holds good, as usual, up to a point at which the load is about one-half the maximum. The curve of times and loads exhibits the rate of loss of effort while the bar was finally held at a deflection of 0.5456 inch, the load being carefully and regularly reduced, as the effort diminished, from 1,233 to 911 pounds, at which latter figure the bar broke. The curve is a very smooth one.

EFFECT OF TIME ON BRASS.

BAR NO. 599.

90 parts zinc, 10 parts copper: 1 × 0.992 × 22 inches.

LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.
Pounds.	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*
23	0.0033	.....	363	0.0781	.....	3	.....	0.0336
43	0.0078	.....	403	0.0881	.....	643	0.1641	.....
63	0.0127	.....	3	.....	0.0079	803	0.2149	.....
103	0.0225	.....	403	0.0886	.....	1,003	0.3178	.....
143	0.031	.....	Resistance fell in 8 h. 30 m.			1,103	0.3921	.....
163	0.0347	.....	to 333	0.0886	.....	1,203	0.481	.....
Resistance fell in 15 h. 25 m.			3	.....	0.0246	1,233	0.5209	.....
to 143	0.0347	.....	333	0.0896	.....	Resistance fell in 15 m.		
3	.....	0.0039	Resistance fell in 15 h.			to 1,137	0.5209	.....
163	0.0391	.....	to 302	0.0896	.....	3	.....	0.2736
203	0.0471	.....	303	0.0876	.....	1,137	0.5131	.....
243	0.0544	.....	403	0.1072	.....	1,233	0.5456	.....
283	0.0611	.....	503	0.1282	.....			
323	0.0692	.....	603	0.1521	.....			

The bar was left under strain at $12^h\ 22^m$ A.M., and the effort to restore itself measured at intervals, as follows:

HOUR.—11:37	11:50 A.M.	12:2	12:8	12:25	12:39½	12:53½	12:58½	1:20 P.M.
EFFORT.—1,133	1,093	1,070	1,063	1,043	1,023	1,003	993	911 pounds.

At $1^h\ 23^m$ P.M. the bar broke.

BAR NO. 596.

75 parts zinc, 25 parts copper; second casting; 0.985 × 0.985 × 22 inches.

LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.	LOAD.	DEFLECTION.	SET.
Pounds.	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*	*Pounds.*	*Inch.*	*Inch.*
23	0.0057	.....	463	0.0799	.....	503	0.0894	.....
63	0.0142	.....	503	0.0866	.....	543	0.0952	.....
103	0.0207	.....	3	.....	0.0014	583	0.1012	.....
143	0.0275	.....	503	0.0866	.....	603	0.1042	.....
183	0.0346	.....	Resistance fell in 5 h.			623	0.1075	.....
223	0.0414	.....	to 489	0.0866	.....	643	0.1102	.....
263	0.0485	.....	3	.....	0.0074	663	0.1136	.....
303	0.0549	.....	489	0.0866	.....	Broke 5 seconds after with ringing sound.		
343	0.0610	.....	Resistance fell in 13 h. 30 m.					
383	0.0669	.....	to 473	0.0866	.....			
423	0.073	.....	3	.....	0.0092			

An example of somewhat similar behavior, but exhibited by a metal of very different quality, is shown above.

This bar was hard, brittle, and elastic, but must apparently be classed with tin in its behavior under either continued or intermitted stress.

These latter specimens were broken; one in each set by adding weight steadily until the end of the test, so as to give as little time for elevation of elastic limit as was possible; and one in each set by intermittent stress, observing sets, and the elevation of the elastic limit.

There seems to the Author to exist a distinction, illustrated in these cases, between that "flow" which is seen in these metals, and that to which has been attributed the relief of internal stress and the elevation of the elastic limit by strain and with time.

If the long-known effects of cold-hammering, cold-rolling, and wire-drawing in stiffening, strengthening, and hardening some metals can be, as the Author is inclined to believe, attributed in part to this molecular change, as well as to simple condensation and closing up of cavities and pores, this variation of the elastic limit by distortion under externally applied force has been shown to occur in iron and in metals of that class in tension, torsion, compression, and under transverse strain.

Effect of Prolonged Stress on Tin and Zinc.—In testing a bar of tin, in work done as described in earlier chapters, the Author studied this phenomenon. An experiment on No. 29 A (a bar of pure tin) was made to determine the difference in resistance to slow and rapid rupture. This bar was a good casting, and tests of the two pieces, one from the upper and one from the lower end of the bar, should show little, if any, difference in strength. No. 29 A was tested with a load of 1,700 pounds, which caused an elongation of 0.15 inch. This load was then reduced to 1,250 pounds, and the reading again taken, showing an elongation of 0.19 inch, which increased in two minutes to 0.27 inch. The load was then increased to 1,400 pounds, and the elongation was 0.32 inch. The load was allowed to remain on the bar for ten minutes, and the elongation gradually increased to 1.7 inches, when the bar broke. It seems probable from this test that

the load of 1,400 pounds would have broken the piece, even if the load of 1,700 pounds had not been placed on it at the beginning of the test.

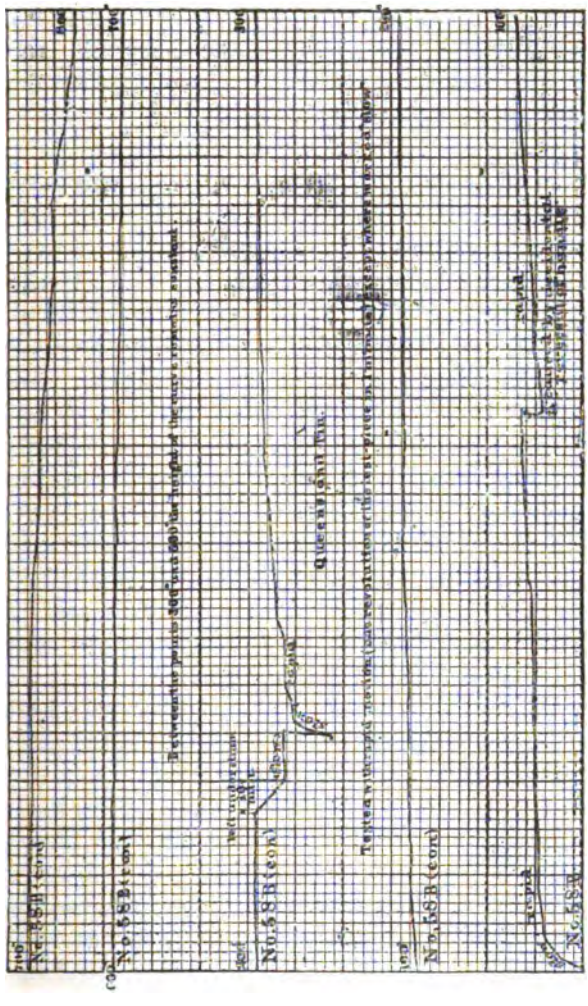


FIG. 108.—AUTOGRAPHIC STRAIN DIAGRAM OF TIN.

Bar No. 29 B was tested in a different manner. The load was gradually, but rapidly, increased to 2,100 pounds, without stopping longer than was necessary to take the reading

of the elongations at 975, 1,180, 1,290, 1,600, and 2,000 pounds. At 2,100 pounds, the elongation read 1.88 inches. The piece then extended very rapidly, and, at the same time, its resistance, as measured by the scale-beam, reduced to 1,700 pounds. The pump of the hydraulic press was worked as fast as possible, but the beam could not be balanced beyond 1,700 pounds. The piece sustained this load a few seconds, then broke after an elongation of 2.58 inches.

Comparing the tests, it is seen that the resistance of No. 29 A to an elongation greater than 0.19 inch was never greater than 1,400 pounds, while that of No. 29 B was 2,100 pounds, or 50 per cent. more than the former; which 50 per cent. apparent increase of strength was evidently due to the greater rapidity of the test of No. 29 B. The fact that the difference in strength is only apparent is confirmed by the experiments by torsional stress on pieces from the same bar. These showed that torsion-pieces No. 29 A and No. 29 B, from the top and from the bottom of the bar, tested by moderately slow motion, each gave a resistance of 14.2 foot-pounds torsional moment; piece No. 29 C, from the middle of the bar, tested in the same manner, resisted 13.2 foot-pounds, while No. 29 D, a piece taken from the middle of the bar and adjoining No. 29 C, tested by very slow motion and left under stress for hours, resisted only 9.2 foot-pounds or some 30 per cent. less than either of the other pieces.

The effect of slow and rapid test is shown by both bars in the tensile test. The average tenacity of all the pieces tested is given as 3,130 pounds per square inch, but it is probable that all the pieces would have broken at as low as 2,000 pounds if the test had been of long duration, say one hour, or as high as 4,000 pounds if each test had been made in, say, five minutes. The records of several tests follow.

The effect of time is also shown in the autographic strain-diagrams (Fig. 108), and in the records calculated from them.

This peculiar property of variation of resistance with time affects a large proportion of the alloys.

With zinc, experiments were made to determine the effect of rapid and of slow stress and of resting under stress. They indicated a decrease of resistance when resting under stress, a uniform resistance to very slow motion, and a rapid increase of resistance to rapid motion, except after the resistance has reached the maximum, when rapid motion then keeps the resistance constant.

It was observed that very ductile metals, such as tin itself and alloys containing a large amount of tin, all exhibit different amounts of resistance to slow and to rapid stress, and a decrease of resistance on resting under stress. The same phenomenon is exhibited by cast zinc, which is much less ductile than the copper-tin alloys, and is less ductile than several of the alloys of copper and zinc (those containing from 20 to 40 per cent. of zinc), which either did not show the phenomenon at all, or but slightly.

The Effect on Bronze of long continued stress in producing continuous distortion, even when the loads are far within those required to produce the same effect on first application, is well exhibited below.

EFFECT OF TIME ON BRONZE.

Tests by Transverse Stress—With Dead Loads.

Samples 1 × 1 × 22 inches.

No. of Test.	Material Parts.		Load.	Deflection.	Time.	Increased Deflection.	Breaking Weight.
	Tin.	Copper.					
			Pounds.	*Inches.*		*Inches.*	*Pounds.*
7	.....	100	600	0.534	5 minutes	0.009	650
8	1.9	98.1	475	1.702	3 minutes	0.291	....
			500	2.108	3 minutes	0.488	500
9	7.2	92.8	950	0.348	5 minutes	0.081	1,350
10	10.	90.	950	0.395	5 minutes	0.021	....
			1,485	3.447	13 minutes	4.087	1,485
11	90.3	9.7	100	0.085	10 minutes	0.021	....
			120	0.140	10 minutes	0.055	....
			140	0.221	10 minutes	0.098	....
			140	0.319	10 minutes	0.038	....
			140	0.357	40 hours	0.920	....

NO. OF TEST.	MATERIAL PARTS.		LOAD.	DEFLECTION.	TIME.	INCREASED DEFLECTION.	BREAKING WEIGHT.
	Tin.	Copper.					
			Pounds.	*Inches.*		*Inches.*	*Pounds.*
			160	1.294	10 minutes	0.025	....
			160	1.320	1 day	1.000	....
			160	2.320	1 day	1.000	....
			160	3.320	1 day	1.000	160
12	98.89	1.11	90	0.243	5 minutes	0.063	....
			120	0.736	15 minutes ...	1.055	....
			120	1.791	30 minutes	0.748	....
			120	2.539	45 minutes ...	0.595	....
			120	3.134	12 hours	8.000	120
13	100	.....	80	0.218	5 minutes	0.064	110

Metals having a composition intermediate between these extremes have not been observed to exhibit flow or to increase deflection under a constant load.

The same phenomena are exhibited by tests made in the autographic testing machine,* thus :

NO. OF TEST.	MATERIAL.		TIME UNDER STRESS.	ANGLE OF TORSION.	FALL OF PENCIL.	REMARKS.
	Tin.	Copper.				
				°		
†1	.....	....	40 hours ...	65	0.06 inch...	Recovered after further distortion of 1°.
†2	100	....	1 hour	180	0.1 inch...	Recovered in 8°.
†3	.....	....	2 hours ...	280	0.1 inch...	Recovered in 80°.
4	99.44	0.56	12 minutes .	‡380	50 per cent.	Did not recover.
5	98.89	1.11	.....	....	.....	Behaved like No. 4.
6	Alloy.		.....	58	0.2 inches.	Did not recover.

Tests by tension with similar materials exhibit similar results, and these observations and experiments thus seem to indicate that, under some conditions, the phenomena of flow, and of variation of the elastic limit by strain, may be coexistent, and that progressive distortion may occur with "viscous" metals.

A Fluctuation of Resistance with Time, illustrated in the table here given, is a singular phenomenon which has been observed by the Author, but the causes of which remain

* M. of E., p. 379. † Same piece. ‡ Taking "elasticity line."

FLUCTUATION OF RESISTANCE.

Test by Transverse Stress.

ALLOY OF COPPER AND TIN.

No. 47.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.996″; Depth, 0.983″.

LOAD.	DEFLECTION. Δ	SET.	MODULUS OF ELASTICITY. $\frac{Pl^3}{4\,\Delta\,bd^3}$
Pounds.	*Inch.*	*Inch.*	
10	0.0027	.....	.....
20	0.0070	.....	8,039,339
40	0.0153	.....	7,356,258
60	0.0256	.....	6,594,770
80	0.0365	.....	6,167,163
	Beam sinks slowly.		
100	0.0499	.....	5,638,814
5	.....	0.0092	.....
120	0.0617	.....	5,472,481
140	0.0804	.....	4,899,597
160	0.1042	.....	4,320,565
180	0.1343	.....	3,777,245
200	0.1666	.....	3,377,873
5	.....	0.0821	.....
200	0.1798	.....	.....
220	0.2145	.....	.....
240	0.2503	.....	2,697,980
260	0.3021	.....	.....
270	0.3367	.....	.....
280	0.3762	.....	832,406
290	0.4147	.....	.....
300	0.4597	.....	.....
5	.....	0.3084	.....

The beam was observed to rise, and another reading of set was taken in 2 minutes.

5	.....	0.3022	.....

The beam rose again, pushed forward the poise till beam balanced at 10 pounds. Time 2 minutes.

In 2 minutes more, beam balanced at 14 pounds. The pressure-screw was then run back till beam balanced again at 5 pounds, and another reading of set taken.

Pounds.	*Inches.*	*Inch.*	
5	.....	0.2998	.....

Beam rose again.
In 2 minutes balanced at 10 pounds.
In 10 minutes balanced at 16 pounds.
In 39 minutes balanced at 23 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	.....	0.2902	.....

In 4 minutes beam rose again.
In 23 minutes beam balanced at 14 pounds.
In 1 hour and 36 minutes beam balanced at 20 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	.....	0.2845	.....

Total *decrease of set* in 2 hours and 20 minutes 0.3084 − 0.2845 = 0.0239 inch.
Replaced load of 280 pounds.

280	0.4849	.....	.....
300	0.5332	.....	.....
310	Broke on applying strain.		

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3\,Pl}{2bd^2} = 10{,}288$.

No. 48.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: Length between supports, 22″; Breadth, 0.985″; Depth, 0.990″.

10	0.0025	.....	.....
20	0.0050	.....	.....
40	0.0141	.....	7,901,458
60	0.0230	.....	7,249,195
80	0.0352	.....	6,330,144
	Beam sinks slowly.		
100	0.0508	.....	5,482,803
5	.....	0.0120	.....
120	0.0760	.....	4,397,784
140	0.0969	.....	4,024,116
160	0.1262	.....	3,531,237
180	0.1592	.....	.....
200	0.2044	.....	2,725,307
5	.....	0.1238	.....
200	0.2268	.....	.....
220	0.2916	.....	.....
240	0.4078	.....	1,639,194
260	0.5210	.....	.....
270	0.5763	.....	.....
280	0.6458	.....	1,207,609
290	0.7185	.....	.....
300	0.8025	.....	1,041,220
5	.....	0.6742	.....

Scale beam rose.
In 2 minutes balanced at 20 pounds.
In 4 minutes balanced at 29 pounds.
In 15 minutes balanced at 34 pounds.
Ran back pressure-screw till beam balanced again at 5 pounds.

5	.....	0.6555	.....

Beam rose again, balanced at 12 pounds in 5 minutes.

5	.....	0.6508	.....

Total decrease of set in 20 minutes, 0.6742 − 0.6508 = 0.0234 inch.
Beam rose again, but test was continued without further waiting.

260	0.8304	.....	.....
280	0 9018	.....	.....
300	1.0760	Beam sank rapidly.	
300	Repeated. Bar broke just as beam rose.		

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 10{,}254$.

to be determined. The bars tested as shown were not perfect in structure, and do not exhibit any considerable strength; they consist principally of tin (82.5 and 87.5 per cent.) and are valueless for the ordinary work of the constructor, although useful "white metals." It is seen that the resistance of both bars was, at times, overcome by the load, but, on balancing the weigh-beam, the bar each time gradually re-acquired a power of raising the load which had deformed it, and straightened itself sufficiently to raise the beam against the upper "chock." A *decrease of set* took place of 0.02 inch—in the first beam in two hours and twenty minutes, and in the second in twenty minutes. In two minutes, recovery occurred to such an extent that the bar exerted an effort of 20 pounds tending to straighten itself, and in 15 minutes of 34 pounds. The phenomenon is one which will demand careful investigation.

The Effect of Unintermitted and Heavy Stress on Resistance is well exhibited on the two sets of strain-diagrams* here reproduced from Part II. of M. of E. The first series of tests exhibited *decrease of resistance* with time.

No. 655 was a bar of Queensland tin, presented to the Author by the Commissioner of that country at the Centennial Exhibition, and which was found to be remarkably pure. A load of 100 pounds gave a deflection of 0.2109 inch, and produced a set of 0.1753 inch. The same load restored deflected the bar 0.2415 inch, which deflection being retained, the effort to regain the original shape decreased in one minute from 100 to 70 pounds, in 3 minutes to 62, and in 8 minutes to 56 pounds. The original load of 100 pounds then brought the deflection to 0.3033 inch, nearly 50 per cent. more than at first.

A bar, No. 599, of copper-zinc alloy, similarly tested, deflected 0.5209 inch under 1,233 pounds, and took a set of 0.2736 inch after being held at that deflection 15 minutes, the effort falling meantime to 1,137 pounds. Restoring the load of 1,137 pounds, the deflection became 0.5131 inch, and the original load of 1,233 pounds brought it to 0.5456 inch.

* Trans. American Society of Civil Engineers, 1877.

The bar was now held at this deflection and the set gradually took place, the effort falling in 15 minutes to 1,132 pounds (4 per cent. more than at the first observation), in 22 minutes to 1,093, in 46 minutes to 1,063, in 63 minutes to 1,043, in 91½ minutes to 1,003, and in 118 minutes to 911 pounds, at which last strain the bar broke 3 minutes later, the deflection remaining unchanged up to the instant of fracture. This remarkable case has already been referred to in an earlier article, when treating of the effect of time in producing variation of resistance and of the elastic limit.

Nos. 561, copper-tin, and 612, copper-zinc, were compositions which behaved quite similarly to the iron bar at its first trial, the set apparently becoming nearly complete, in the first after 1 hour, and in the second after 3 or 4 hours.

In all of these metals, the set and the loss of effort to resume the original form were phenomena requiring time for their progress, and in all, except in the case of No. 599—which was loaded heavily—the change gradually became less and less rapid, tending constantly toward a maximum.

So far as the observation of the Author has yet extended, the latter is always the case under light loads. As heavier loads are added, and the maximum resistance of the material is approached, the change continues to progress longer, and, as in the case of the brass above described, it may progress so far as to produce rupture, when the load becomes heavy, up to a limit, which closely approaches maximum tenacity in the "iron class." The brass broke under a stress 25 per cent. less than it had actually sustained previously.

The records are herewith presented, and the curves representing them shown in the figures which follow.

DECREASE OF RESISTANCE AND INCREASE OF SET OF METALS, WITH TIME.

Bars 1 inch square; 22 inches between supports.

TIME.	LOAD.	LOSS OF LOAD.	DEFLECTION.	SET.
	No. 648 WROUGHT IRON.			
	First Trial.			
Min.	*Pounds.*	*Pounds.*	*Inches.*	*Inch.*
.....	1,003	...	0.0395	.....
.....	3	...	.....	0.0049
.....	1,003	...	0.1001	.....
25	999	4	0.1001	.....
100	991	12	0.1002	.....
275	987	16	0.1001	.....
320	987	16	0.1001	.....
320	3	...	.....	0.007
322	987	...	0.9910	.....
322	1,003	...	0.1003	.....
.....	2,720	...	2.6400	.....
	Second Trial.			
.....	1,003	...	2.2548	.....
	No. 561.—27.5 PARTS COPPER, 72.5 PARTS TIN.			
.....	160	...	0.0696	.....
.....	5	...	.....	0.0145
.....	160	...	0.072	.....
1	154	6	0.072	.....
3	150	10	0.072	.....
2,640	104	56	0.072	.....
4,140	100	60	0.072	.....
.....	5	...	.....	0.04
.....	100	...	0.0763	.....
.....	160	...	0.0970	.....
.....	320	...	0.2200	Broke
	No. 599.—10 PARTS COPPER, 90 PARTS ZINC.			
.....	1,233	...	0.5209	.....
15	1,137	...	0.5209	.....
.....	3	...	.....	0.2736
.....	1,137	...	0.5131	.....
.....	1,233	...	0.5456	.....
15	1,133	100	0.5456	.....
28	1,093	140	0.5456	.....
40	1,070	163	0.5456	.....
46	1,063	170	0.5456	.....
63	1,043	190	0.5456	.....
77.5	1,023	210	0.5456	.....
91.5	1,003	230	0.5456	.....

TIME.	LOAD.	LOSS OF LOAD.	DEFLECTION.	SET.
Min.	*Pounds.*	*Pounds.*	*Inches.*	*Inch.*
.....	3	...	.....	0.1051
.....	1,603	...	0.287	.....
1	1,521	82	0.287	.....
2	1,493	110	0.287	.....
3	1,483	120	0.287	.....
23	1,463	140	0.287	.....
53	1,461	142	0.287	.....
133	1,459	144	0.287	.....
193	1,457	146	0.287	.....
363	1,457	146	0.287	.....
363	3	...	.....	0.1481
.....	1,457	...	0.2863	.....
.....	1,603	.	0.3016	.....
.....	2,720	...	2.6400	.....
.....	.....	...	.....	.....
96.5	993	240	0.5456	.....
118	911	322	.....	.....
121	911	326	.....	Broke
	No. 612.—47.5 PARTS COPPER, 52.5 PARTS ZINC.			
.....	800	...	0.3332	.....
.....	3	...	.....	0.1478
.....	800	...	0.3366	.....
5	790	10	0.3366	.....
25	778	22	0.3366	.....
120	766	34	0.3366	.....
480	756	44	0.3366	.....
1,320	751	49	0.3366	.....
.....	3	...	.....	0.1688
.....	751	...	0.3364	.....
.....	800	...	0.3490	.....
.....	1,100	...	.....	Broke
	No. 655.—QUEENSLAND TIN.			
.....	100	...	0.2109	.....
.....	3	...	.....	0.1753
.....	100	...	0.2415	.....
1	70	30	0.2415	.....
3	62	38	0.2415	.....
8	56	44	0.2415	.....
.....	100	...	0.3033	.....
.....	150	...	Bent rapidly.	

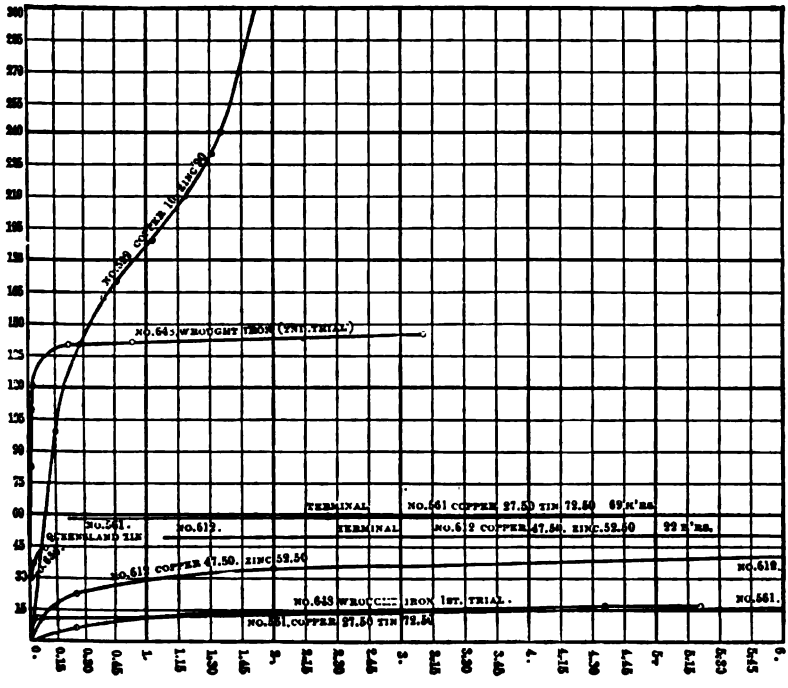
The Observed Increase of Deflection Under Static Load.—In the preceding article the writer presented results of an investigation made to determine the time required to

produce "set" in metals belonging to the two typical classes, which exhibit, the one exaltation, and the other a depression of the elastic limit under strain.

The experiments there described were made by means of

FIG. 109.—DECREASE OF RESISTANCE WITH TIME.

Rate of set of Bars 1 inch square 22 inches between supports.



a testing-machine, in which the test-piece could be securely held at a given degree of distortion, and its effort to recover its form measured at intervals, until the progressive loss of effort could no longer be detected, and until it was thus indicated that set had become complete.

The deductions were:

That in metals of all classes under light loads this de-

crease of effort and rate of set become less and less noticeable until, after some time, no further change can be observed, and the set is permanent.

That in metals of the "tin class," or those which had been found to exhibit a depression of the elastic limit with intermitted strain, under a heavy load, *i. e.*, a load considerably exceeding the proof strain, the loss of effort continued, until, before the set had become complete, the test-piece yielded entirely.

And that in the metals of the "iron class," or those exhibiting an elevation of elastic limit by strain, the set became a maximum and permanent, and the test-piece remained unbroken, no matter how near the maximum load the strain may have been.

The experiments here described were conducted with the same object as those above referred to. In these experiments, however, the load, instead of the distortion, was made constant, and deflection was allowed to progress, its rate being observed, until the test-piece either broke under the load or rapidly yielded, or until a permanent set was produced. The results of these experiments are in striking accordance with those conducted in the manner previously described. They exhibit the fact of a gradually-changing rate of set for the several cases of light or heavy loads, and illustrate the striking and important distinctions between the two classes of metals even more plainly than the preceding. The accompanying record and the strain-diagrams, which are its graphical representation, will assist the reader in comprehending the method of research and its results. All test-pieces were of one inch square section, and loaded at the middle. The bearings were 22 inches apart.

No. 651 was of wrought iron from the same bar with No. 648.* This specimen subsequently gave way under a load of 2,587 pounds. Its rate of set was determined at about 60 per cent. of its ultimate resistance, or at 1,600 pounds. Its deflection, starting at 0.489 inch, increased in the first minute, 0.1047; in the second minute, 0.026; in the third minute,

* Trans. Am. Soc., C. E., vol. v.. page 208.

0.0125; in the fourth minute, 0.0088; in the fifth minute, 0.0063; and in the sixth minute, 0.0031 inch; the total deflections being 0.5937, 0.6197, 0.6322, 0.641, 0.6473, and 0.6504, inch. In the succeeding 10 minutes the deflection only increased 0.0094 inch, or to 0.6598 inch, and remained at that point without increasing so much as 0.0001 inch, although the load was allowed to remain 344 minutes untouched. The bar had evidently taken a permanent set, and it seems to the writer probable that it would have remained at that deflection indefinitely, and have been perfectly free from liability to fracture for any length of time.

This bar finally yielded completely, under a load of 2,589 pounds, deflecting 4.67 inches.

No. 479 was a bronze bar containing 3¾ per cent. of tin. Its behavior may be taken as typical of that of the whole "tin class" of metals, as the preceding illustrates the behavior of the "iron class" under heavy loads. It was subjected to two trials, the one under a load of 700 and the other of 1,000 pounds, and broke under the latter load, after having sustained it 1¼ hours. The behavior of this bar will be considered especially interesting, if its record and strain-diagram are compared with those of No. 599, previously given, which latter specimen broke after 121 minutes, when held at a constant deflection of 0.5456 inch; its resistance gradually falling from an initial amount of 1,233 pounds, to 911 pounds at the instant before breaking.

This bar, No. 479, was loaded with 700 pounds "dead weight," and at once deflected 0.441 inch. The deflection increased 0.118 inch in the first five minutes, 0.024 in the second five minutes, 0.018 in the second ten minutes, 0.17 in the fourth, 0.012 in the fifth, and 0.008 inch in the sixth ten minute period, the total set increasing from 0.441 to 0.65 inch. The record and the strain-diagram show that at the termination of this trial the deflection was regularly increasing. The load was then removed and the set was found to be 0.524 inch, the bar springing back 0.126 inch on removal of the weight.

The bar was again loaded with 1,000 pounds. The first

deflection which could be measured was 3.118 inches and the increase at first followed the parabolic law noted in the preceding cases, but quickly became accelerated; this sudden change of law is best seen on the strain-diagram. The new rate of increase continued until fracture actually occurred, at the end of 1¼ hours, and at a deflection of 4.506 inches.

This bar was of very different composition from No. 599; it is a member of the "tin class," however, and it is seen, by examining their records and strain-diagrams, that these specimens, tested under radically different conditions, both illustrate the peculiar characteristics of the class, by similarly exhibiting its treacherous nature.

No. 504 was a bar of tin containing about 0.6 per cent. of copper—the opposite end of the scale—and exhibited precisely similar behavior, taking a set of 0.323 inch under 110 pounds and steadily giving way and deflecting uninterruptedly until the trial ended at the end of 1,270 minutes, over 21 hours. This bar, subsequently, was, by a maximum stress of 130 pounds, rapidly broken down to a deflection of 8.11 inches.

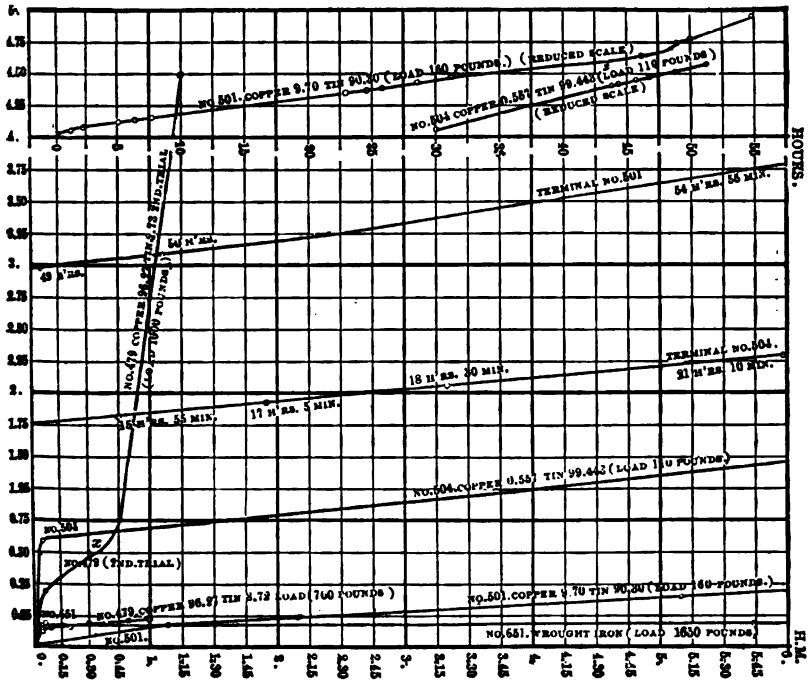
No. 501 presents the finest illustration of this phenomenon yet met with by the Author. The test extended over nearly 2½ days under observation, and the bar left for the night was found next morning broken. The time of fracture is therefore unknown, as is the ultimate deflection. The record is, however, sufficient to determine the law, and the strain-diagram is seen to be similar to that of the second test of No. 479, exhibiting the same tendency to the parabolic shape and the same change of law and reversal of curvature preceding final rupture, and illustrates, even more strikingly, the fact that this class of metals is not safe against final rupture, even though the load may have been borne a considerable time, and have apparently been shown, *by actual test*, to be capable of sustaining it. A strain-diagram of each of the latter two bars is exhibited on a reduced scale to present to the eye more strikingly this important characteristic.

A comparison of the records and the strain-diagrams with

those of the preceding article, in illustration of the behavior of the two classes of metals under constant deflection, is most

FIG. 110.—INCREASE OF DEFLECTION WITH TIME.

Rate of Set of Bars 1 Inch Square 22 Inches Between Supports.



instructive. It will still be necessary to make many experiments to determine under what fraction of their ultimate resistance to rapidly applied and removed loads, the members of the "tin class"—the viscous metals—will be safe under static permanent loads.

INCREASE OF DEFLECTION WITH TIME.

Bars, 1 inch square; 22 inches between supports. Load applied at the middle.

No. 651.—WROUGHT IRON.

Load, 1,600 *pounds.*

TIME.	DEFLECTION.	INCREASE. Difference.	INCREASE. Total.
Min.	*Inches.*	*Inches.*	*Inches.*
0	0.4890	.....	.....
1	0.5937	0.1047	0.1047
2	0.6197	0.0260	0.1307
3	0.6322	0.0125	0.1432
4	0.6410	0.0088	0.1520
5	0.6473	0.0063	0.1583
6	0.6504	0.0031	0.1614
16	0.6598	0.0094	0.1708
344	0.6598	0.0000	0.1708

Maximum load, 2.589 pounds; maximum deflection, 4.67 inches.

No. 504.—0.557 PARTS COPPER, 99.443 PARTS TIN.

Load, 110 *pounds.*

0	0.323	.....	.....
5	0.406	0.083	0.083
845	1.945	1.539	1.622
865	2.005	0.059	1.681
895	2.138	0.134	1.815
1,025	2.248	0.110	1.925
1,110	2.378	0.130	2.055
1,270	2.626	0.248	2.303

Maximum load, 130 pounds; maximum deflection, 8.11 inches.

No. 479.—96.27 PARTS COPPER, 3.73 PARTS TIN.

Load, 700 *pounds.*

0	0.441	.....	.....
5	0.559	0.118	0.118
10	0.583	0.024	0.142
20	0.601	0.018	0.160

TIME.	DEFLECTION.	INCREASE. Difference.	INCREASE. Total.
Min.	*Inches.*	*Inches.*	*Inches.*
30	0.618	0.017	0.177
40	0.630	0.012	0.189
50	0.642	0.012	0.201
60	0.650	0.008	0.209
Set	0.524	.....	.....

Second Trial.—Load, 1,000 *pounds.*

0	3.118	.....	.....
5	3.540	0.422	0.422
15	3.660	0.120	0.542
45	4.102	0.442	0.984
75	7.634	3.522	4.506

Broke bar under 1,000 pounds.

No. 501.—9.7 PARTS COPPER, 90.3 PARTS TIN.

Load, 160 *pounds.*

0	1.294	.....	.....
10	1.319	0.025	0.025
70	1.463	0.144	0.169
130	1.530	0.067	0.236
310	1.691	0.161	0.397
400	1.766	0.075	0.472
460	1.811	0.045	0.517
1,360	2.534	0.723	1.240
1,475	2.697	0.163	1.403
1,565	2.782	0.085	1.488
1,730	2.938	0.156	1.644
1,880	3.136	0.198	1.842
2,780	3.798	0.662	2.504
2,940	4.274	0.476	2.980
3,000	4.349	0.075	3.055
3,295	5.097	0.748	3.803

Bar left under strain at night and found broken in the morning.

Depression of Elastic Limits.—The effects of intermitted stress and of interrupted strain are of peculiar interest and importance with the non-ferrous metals and the alloys. So far as they have been observed by the Author, they are often precisely the opposite of those noted in experiments on merchant iron and commercial grades of steel. They are well illustrated in Fig. 111, which is here reproduced from Part II., Mat. of Eng.

These strain-diagrams are obtained by transverse test, from bars of common iron, Nos. 648, 649, 650, 651, and from two specimens of bronzes, Nos. 596, 599, all of the same size,

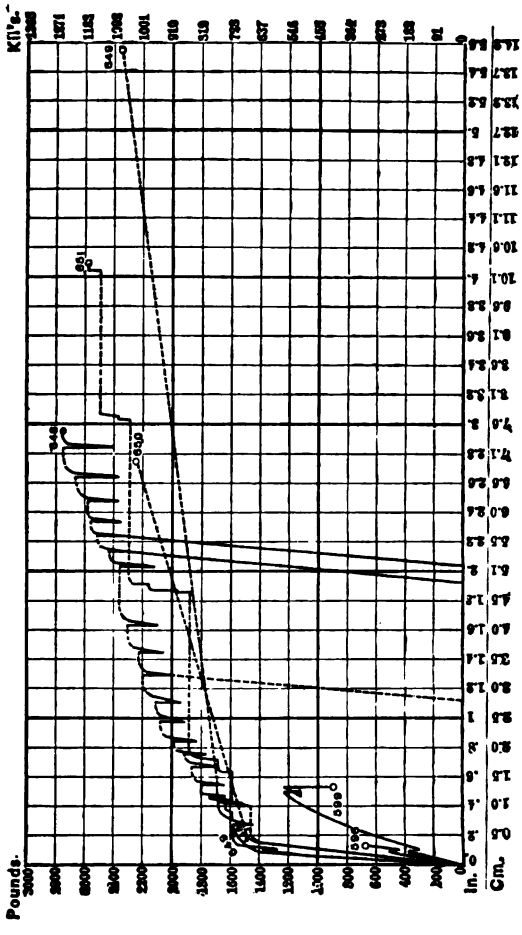


FIG. III.—VARIATION OF ELASTIC LIMITS.

1 inch (2.54 cm.) square and 22 inches (55.9 cm.) between supports.

The first strain diagram to be studied is that of a bar of the most ductile metal (No. 599, copper, 10; zinc, 90). It exhibits clearly the phenomenon of flow with a depression of the elastic limit under constant load.

This bar was left deflected under a load of 163 pounds (74 kgs.). It gradually lost its power of restoration until it only exhibited an effort of 143 pounds (65 kgs.). The curve exhibits the relation of deflection to deflecting force. The resistance gradually increased as deflection progressed until the load—403 pounds (183 kgs.)—produced a deflection of 0.09 inch (0.23 cm.). The bar was again left, and, under a fixed deflection, again lost resisting power, and the effort to straighten itself fell to 333 pounds (151 kgs.).

Finally, the bar offered its maximum resistance of 1,233 pounds (560 kgs.) under a deflection of 0.545 inches (1.3 cm.), and was then held in its flexed position. Gradually its effort to restore itself grew less and less, until, when it had fallen to 911 pounds (414 kgs.), the bar suddenly snapped and the two halves fell to the floor.

No. 596 (copper 25, zinc 75) similarly exhibited a depression of the elastic limit by strain, but, vastly harder, more elastic and brittle, it broke under 663 pounds (301 kgs.) and at a deflection of 0.1136 inch (0.3 cm.), before apparently passing the point termed the primitive or apparent limit of elasticity by the Author, *i.e.*, that point at which the sets become nearly proportional to the strains, and at which the line of the strain-diagram turns sharply away from the vertical.

The strain-diagram No. 648, common iron, is that of the type of that class in which the elevation of the elastic limit has been detected by the Author.

The bar was like the preceding, of 1 inch (2.54 cm.) square section and 22 inches (55.88 cm.) in length between bearings. It reached its elastic limit at 1,450 pounds (659 kgs.) and at a deflection of 0.15 inch (0.4 cm.). Passing this point, and at a deflection of 0.287 inch (0.7 cm.), the bar was held at a constant deflection, under a load of 1,600 pounds (727 kgs.). Flow occurring, the effort to regain its original shape became less and less, until in six hours it had fallen to 1,457 pounds (662 kgs.). Continuing the test, resistance and deflection increased as indicated by the curve, instead of following the original direction.

Similar increase of resisting power under strain is seen at

other points on the curve, and whenever the process of distortion was interrupted long enough to permit flow and that re-arrangement of particles which has been described. An hour or two usually gave time enough to bring out this remarkable phenomenon.

This action has been discovered in iron and steel, and under every form of strain—tension, torsion, compression and cross-breaking—and it would seem that aside from accidental overstrain, producing incipient rupture or loss of strength due to such action as abrasion or corrosion, length of life of iron structures under strain was in itself, apparently, a source of increased safety. On the other hand, as is here seen, the behavior of non-ferrous metals is precisely the opposite, and the engineer is compelled to use them with greater caution and to base his calculations upon a higher factor of safety, a conclusion fully corroborated by the work of Wöhler.

Recurring to Fig. 111, a resemblance is to be noted in the behavior of both classes of metals.

The bars No. 649, 650 and 651 were tested by rapidly increased load up to the breaking point, allowing no time for reading of sets.

The first of this set deflected 0.014 inch (0.04 cm.) under 100 pounds (45 kgs.), 0.052 under 500 pounds, 0.098 under 1,000 pounds, and 0.18 under 1,500 pounds. At 1,600 pounds the deflection was 0.2854 inch, and the bar yielded to the stress, and the deflection became 0.363 in 2¾ minutes. Under 1,640 pounds the deflection increased in six minutes from 0.383 to 0.440 inch, and a maximum resistance was recorded of 2,350 pounds (1,070 kgs.), and a deflection of 5.577 inches (15 cm.). This bar was tested in a similar manner to the preceding, and in the same machine.

Numbers 650 and 651 were tested by dead loads—*i. e.*, by laying upon them heavy weights. By this method the deflection could increase to a maximum under each load, instead of being kept constant, as in the testing machine. No. 650 was rapidly broken without allowing time for completion of set or any considerable exaltation of the elastic limit. The plotted curves of results exhibited well the striking difference

of behavior between this bar and 651, which was purposely given time for set and for exaltation of the elastic limit. At 1,500 pounds (682 kgs.) each had deflected nearly the same amount, and had passed the elastic limit, as usually called. The first, however, gave way completely with 2,260.5 pounds (1,027 kgs.), while the second, after several times exhibiting an elevation of the elastic limit—as at 1,500, 1,600, 1,700, 1,900, 2,300, 2,400 and at 2,500 pounds—finally only yielded entirely at 2,589. The first only deflected 2¾ inches (7 cm.); the second, 4.67 inches (11.9 cm.); although when the latter was loaded with about the weight at which the first yielded, it deflected about the same amount.

The last bar was left two and a half days under its final load, and its deflection increased from 4.275 inches (10.9 cm.) to 4.67 (11.9 cm.), when the weights reached the supports of the frame and the test was ended. The other bar sank rapidly after being loaded with 1,600 pounds (726 kgs.).

Both classes of metals, when flexed, were shown to exhibit less and less effort to restore themselves to their original form. In the case of the tin class, as the Author has called it, this continues indefinitely. With the iron group this loss of effort gradually becomes less and less and reaches a limit at which the bar is found to become stronger than at first. The two classes are thus seen to be affected by time in precisely the same manner initially, but finally in exactly opposite ways.

The Effect of Variable Stress *in causing variation of the normal series of elastic limits* observed during ordinary tests is well shown by the records of test of the copper-zinc alloys. The following are extracts from the memoranda taken during tests made for the U. S. Board to which frequent references are made. Similar illustration may be found among the records of tests, both of bronzes and of brasses, already given.

Bar No. 8 (60.94 copper, 38.65 zinc) bent to a deflection of 3½ inches under a load of 1,140 pounds. The apparent elastic limit was reached at about 640 pounds. At 400 pounds the bar was left under stress for eighteen hours, at the

end of which time no change had occurred. At 800 pounds, the beam fell and the resistance decreased 18 pounds in an hour. It finally broke under about 1,200 pounds.

Bar No. 19 (10.30 Cu., 88.88 Zn.) at 1,233 pounds yielded. In an hour and a half the decrease of resistance was nearly 250 pounds, the decrease of resistance then in twenty-two minutes being 82 pounds. In three minutes after taking the last reading, when it balanced at 911 pounds, the bar suddenly broke without warning. The deflection was unchanged during this entire "time test." The elastic limit was reached at about 900 pounds.

The Effect of Repeated Strain is greater with the non-ferrous metals, and usually with the alloys, than with iron and steel. The investigations of Wöhler and Spangenberg were made principally upon the latter class of materials, but were also made to cover the action of a few other metals.

Wöhler's law, that the rupture of a piece may be produced by the repeated action of a load less than that which, once applied, would cause fracture, is true, probably, of all the non-ferrous metals, and this effect is with them much more serious than with the ferrous metals. Spangenberg found that gun bronze in tension would endure a stress of 22,000 pounds per square inch (1,547 kgs. per sq. cm.) laid on and at once removed 4,200 times before rupture; a stress of 16,500 pounds (1,160 kgs.) 6,300 times, and 11,000 pounds per square inch (773 kgs. per sq. cm.), 5,547,600 times. It may be considered safe under indefinitely repeated loads falling well under one-half its tenacity as determined by ordinary test. Phosphor bronze, forged, bore 53,900 repetitions of the smallest of the above loads, and 2,600,000 of the next load, but broke under 1,621,000 repetitions of a load of 13,750 pounds per square inch (967 kgs. per sq. cm.). The cast metal sustained 408,350, 2,731,161 and 2,340,000 repetitions of the same loads. This peculiar behavior is not explained by the experimenter.

Further experiment in this direction is desirable. Meantime, the engineer will probably find it advisable to allow, for intermittent loads, but one-half the stresses which would be

permitted for single applications of load, and one-quarter where suddenly applied, while the factor of safety should be probably not less than one-half greater for non-ferrous material than with iron. The limits of stress sometimes proposed are not far from the following, which may be compared with the values already given for factors of safety and ultimate strength.

PERMISSIBLE REPEATED STRESSES FOR NON-FERROUS METALS.

	FACTOR OF SAFETY.		MAXIMUM STRESS.			
			Dead Load.		Live Load.	
	Dead Load.	Live Load.	Lbs. per sq. in.	Kgs. per sq. cm.	Lbs. per sq. in.	Kgs. per sq. cm.
Copper, cast.....	4	8	5,000	352	2,500	176
" forged.....	4	8	15,000	1,055	7,500	528
" wire	4	8	16,000	1,125	8,000	563
Gun-bronze, cast.....	4	8	10,000	703	5,000	352
Brass, yellow, cast...	4	8	5,000	352	2,500	176
" " rolled.	4	8	10,000	703	5,000	352
" " wire ..	4	8	12,000	845	6,000	423
Lead, rolled.....	4	8	1,000	70	500	35

When the stresses are reversed, as in connecting rods, the factor of safety should be doubled and the maximum stresses reduced at least one-half.

THE MATERIALS OF CONSTRUCTION.

PART II.

NON-METALLIC MATERIALS.

CHAPTER XVIII.

STONES AND CEMENTS.

Use by Constructing Engineers.—The mechanical engineer makes comparatively little use of the materials of masonry. Their principal value to him is for use in foundations, and in structures protecting his machinery.

Of the stones, but few are well adapted to his purpose. Using them in foundations, he requires them to be strong and dense, hard and durable; and the mortars and cements used to bind them should be of the best possible quality. A foundation intended to bear the shock and tremor of moving machinery must, necessarily, be more carefully built, and must be constructed of more carefully selected materials than a foundation carrying a load at rest.

The civil engineer makes frequent use of all the materials of masonry.

There is given here a summary of the most important characteristics of these materials. For a more detailed account of them, reference may be made to special works on civil engineering. The mason uses for foundations natural stones which are either silicious, calcareous, or argillaceous in their character, and artifical stones, including the several varieties of brick. For special construction, he sometimes employs materials not in common use, as fire brick and fire clay. These materials are very rarely used in structures, to resist other than compressive stress.

Classification of Stones.—The system of Durocher and Bunsen classifies the stones by reference to their proportions of silica, and under a geological classification into igneous, metamorphic, sedimentary, and calcareous. The igneous or plutonic rocks were produced by original solidification from fusion or by later volcanic action. The metamorphic rocks are sedimentary, but have been altered by heat, pressure, chemical, and other agencies. The sedimentary rocks are the result of the abrasion of older rocks by water, and subsequent condensation and solidification under pressure. The calcareous rocks are composed of corals, as the "Coquina," or of the shells of marine animals which have usually, under the pressure of superincumbent rock and soil, become so compacted as to have lost their form, and to have united into dense and granular masses.

Silicious Stones.—The granitic group of igneous rocks is richest in silica, and its members are known as silicious stones. Of this class, granite, sienite, gneiss, greenstone, and trap, and the harder varieties of sandstone, are most commonly used.

Granite is a primary rock, and underlies the stratified rocks; it is, itself, unstratified. It is of a compact crystalline structure, and is composed of quartz, feldspar, and mica; its principal impurities are talc and hornblende. Its quartz is in the form of colorless or gray crystals; its feldspar is in opaque-white or flesh-colored crystals; and the mica appears as shining scales or grains.

Its quality varies considerably according to the proportions and mode of aggregation of its constituents. The greater the proportion of quartz, and the less the proportion of feldspar and mica, the greater the durability and hardness of the stone. Feldspar renders the stone lighter in color and easier to cut, and more susceptible to decomposition by solution of the potash contained in it; mica renders it friable; and hornblende heavy and tough.

The best kinds of granite are the most valuable of all our building stones, and it is extensively used for important works. Under exposure to fire it is, however, less durable

than many, in other respects, inferior stones. It is easy to quarry, and blocks may be obtained of any size. It is difficult to work, and therefore very costly to use if the stone must be dressed. Its specific gravity is about 2.66, and its weight 166 pounds per cubic foot, or nearly 2 tons per cubic yard (2659 kilogrammes per cubic metre).

Granite is found throughout all the Eastern States, in Canada, in many parts of the Alleghanies and Rocky Mountains, and usually wherever the later rock formations have been removed and left the underlying beds exposed. It is generally classified into gray and red.

Gray granite in immense quantities is found in Maine. That from Dix Island is very hard and strong. The granite of Hallowell has a greenish tint, and is very light-colored when first cut; it is fine-grained and durable, yet easily worked. Morgan's Bay granite is very strong, easily worked, and light-colored. Round Pond granite is fine-grained and polishes well. Gray granite of good quality is also found at Mt. Desert, Clark's and Fox Islands. In New Hampshire, the "Granite State," a fine granite is found at Pelham. Much of that found in this State is coarse, micaceous, and not very durable. In Vermont, the Barre granite is perhaps the best; it is light-colored and homogeneous. In Massachusetts, the Quincy granite has the greatest reputation. It has a dark bluish-gray color, is very durable, and takes a fine polish. In Rhode Island, at Westerly, is found granite of the very best quality; it is fine-grained, containing small particles of hornblende and black mica. It is much used for monumental purposes. In Connecticut, a very fine-grained granite is quarried at Mystic Bridge. That obtained at Millstone Point is rather dark in color, compact, with comparatively little hornblende or mica. In New Jersey, an excellent granite is found at Newfoundland.

Red granite of excellent quality is found along the Bay of Fundy. It is composed of red orthoclase, bluish quartz, and a little hornblende, with scarcely any mica. It is hard, and takes a fine polish. Similar granite is found on Forsyth's Island in the St. Lawrence. The Calais red granite comes

from near the St. Croix River in Maine. Very fine red granites are found at Lake Superior, and at many points in the Rocky Mountains. The Scotch Peterhead red granite is used considerably, but is not greatly superior to many of our native stones.

Talcose Granite, or Protogine, is one in which the mica is replaced by talc.

Sienite was first quarried at Siena or Syene in Egypt, whence its name. It is a granular rock closely resembling granite, and consists of feldspar and hornblende, with frequently quartz and mica. It is hard, tough, rather coarse-grained, and not susceptible of taking a polish. When the feldspar is not too readily decomposed by the removal of its potash when acted upon by the weather, it is the most durable of our granitic rocks, and affords an excellent material for rough and substantial work. Before making use of this stone, if it is obtained from a new quarry, its quality should be carefully tested.

Gneiss and Mica Slate are similar to granite in composition, are metamorphic rocks, and are found stratified. Granite, sienite, and gneiss resemble each other so closely that they are all frequently called granite by those who are not familiar with mineralogy.

Gneiss is less valuable than granite, as it cannot be obtained as readily in blocks of definite size, and as it does not as readily split in directions other than that of stratification. It is, however, a good building material, and, for the purposes of the engineer, answers frequently as well as granite.

Sienitic gneiss is a stratified sienite in which hornblende takes the place of mica.

A very slightly stratified gneiss is found at Concord, New Hampshire, and there are quarries of dark compact gneiss at Greenwich, Connecticut.

These stones are all much affected in quality by the presence of foreign elements. The oxides of iron are particularly injurious, causing discoloration and serious disintegration of the stone. Quarries of excellent granite, sienite, and gneiss

are found throughout the mountain ranges which extend along the coast of the United States.

Greenstone, Trap, and Basalt are plutonic unstratified rocks, consisting of hornblende and feldspar.* In the first named, the grains are not as coarse as in granite, and the others hardly exhibit the granular structure to the eye. The first two break up into blocks, and the latter into columns of prismatic form. They are found in veins and dykes, injected among stratified rocks of all ages. In color, they vary from nearly white, in some varieties of greenstone, to as nearly black in basalt, the difference of color being determined by variations in the proportion of hornblende and feldspar, the former being dark, the latter light, in color. The green of these stones is due to the chromium which is present. The "Palisades," the bluff skirting the western shore of the Hudson River, opposite and above New York, is composed of trap rock. Greenstone also is found in considerable quantities in the same locality, and in the Orange Mountain of New Jersey. These stones make a very durable building material, but cannot be obtained in large blocks, and are very difficult to cut. They form excellent metalling for macadamized roads, and the last two are especially useful for block pavement.

The Porphyries contain from 60 to 80 per cent. silica, 10 to 20 per cent. alumina, and the remaining constituents are iron-oxide, lime, magnesia, soda, and potash in small proportions, and have some value in construction. Their specific gravity ranges from 2.5 to 2.6. They are used principally for ornamental purposes. A fine quality of this stone is obtained near Boston.

Sedimentary Rocks.—*Sandstone* was formed in all of the later geological periods; it is a stratified rock, consisting of grains of sand derived from the disintegration of silicious rock, and cemented together by a natural cement composed usually of silica, lime, and alumina. In the most durable kinds of sandstone, this cement is found to be almost pure

* *School of Mines Quarterly* makes Trap the *generic* name for these rocks.

silica, and in the weaker stones it consists quite largely of alumina.

Lime, when present in this cement, renders the stone peculiarly liable to disintegration when exposed to an impure atmosphere, or when it is used for foundations washed by water containing acids capable of attacking the lime. The presence of clay (silicate of alumina) or of protoxide of iron, is very injurious.

Sandstones vary in quality between very wide limits, some being nearly as valuable as granite, and other kinds being the most friable of our building stones. A small grain, a minute proportion of cementing material, and a sharp, clear, bright fracture are the characteristics of the best stone. Such stone is usually found in thick beds, exhibiting but slight evidence of stratification.

Water readily penetrates between the layers of this stone. In foundations, care should therefore be taken to lay it on its "natural bed," that such penetration of moisture and consequent disintegration by freezing, may, as far as possible, be prevented.

The strength and durability of good sandstone, together with the ease with which it is cut and dressed, makes it the most commonly used of all our building stones. It is frequently denominated "free-stone," from the facility with which it is worked, and "brownstone" when of that color.

The colors of sandstones vary greatly. The Ohio or Amherst and Nova Scotia sandstones are of a yellowish or cream-color, or nearly white. Missouri furnishes a durable stone of a fine yellowish drab color. The stones from Portland, Connecticut; Newark, New Jersey; and from Marquette and Bass Islands in Lake Superior, are dark brownish red. A purplish red stone is found along the Rappahannock and Acquia Creek, which is, however, not of the best quality. A very hard and durable, highly silicious, reddish sandstone is obtained at Potsdam, New York. A dark brownish stone is found at Hummelstown, Pennsylvania.

Soapstone, the silicate of magnesia, is a very widely distributed stone in the United States, and is very valuable

where a stone capable of resisting high temperatures is required.

Calcareous Stones consist largely of lime; limestones and marbles are familiar examples.

Limestones—carbonates of lime—effervesce freely when attacked by acids which are capable of displacing carbonic acid from its combinations. The carbonic acid may also be expelled by high temperature. In the former case, new lime salts are formed by the union of the lime with the attacking acid; in the latter case, caustic lime, "quick-lime," is left uncombined. The limestones vary greatly in their qualities as building materials. While some are as strong and hard as granite, others are as soft and friable as the weakest sandstone. They are, usually, easily worked. There are two sorts: the granular and the compact; both of which classes yield excellent stones.

Those limestones which take a smooth surface and a fine polish are usually called marble; the coarser kinds are known as common limestone. The granular varieties are generally superior in quality, for building purposes, to the compact. The impure carbonates of lime are sometimes of great value. The magnesian limestones, or dolomites, are frequently found to be exceptionally excellent.

Chalk is a soft limestone in which pressure has not usually wholly destroyed the organic texture of the minute shells of which it is composed. It is generally too soft for constructive purposes, and can only be used for making lime.

All the varieties of calcareous stone are found in the United States, one of the most extensive deposits being that which follows a line parallel to the Atlantic coast, and near the deposit of primary rocks already referred to; another underlies the Middle States. The marbles are mostly confined to mountainous districts; the common limestones are often found in immense strata as deposited on the bed of the ancient ocean.

Marbles are usually classified into white and colored, or variegated.

White marble is found in the Laurentian rocks of Canada. Most of the white marble used in the Northern Atlantic States comes from the Green Mountain range extending through Vermont, western Massachusetts, western Connecticut, and south-eastern New York. Valuable quarries exist in Vermont, at Brandon, Rutland, Danby, Dorset, and Manchester; in Massachusetts, at Lanesborough, Lee, Stockbridge, Great Barrington, and Sheffield; in Connecticut, at Canaan; and in New York at Pleasantville and Tuckahoe. Lee marble was used for the extension of the Capitol at Washington, and for the City Hall at Philadelphia. Pleasantville and Tuckahoe marbles were used for the St. Patrick Cathedral, New York. The Pleasantville quarries supply the "Snowflake" marble. A fine quality of statuary marble is found at Rutland, Vermont, which is almost equal to the Italian marble of Europe. The marbles become coarser, harder, and more suitable for building purposes as we proceed south from Rutland. In south-eastern New York they are of a dolomitic character. In Delaware is found a coarse dolomitic marble which resembles the Tuckahoe.

Colored marbles.—In Vermont, on the shore of Lake Champlain, is found a brecciated marble, and a dove-colored marble with greenish streaks is quarried at Rutland. Shoreham, Connecticut, supplies a black marble, and a fine marble of the same color is obtained at Williamsport, Pennsylvania. The black Trenton limestone is found at Glen Falls, New York. The Warwick marble from Orange Co., New York, is very beautifully colored with carmine in different shades, veined with white. The Knoxville marble is of a reddish hue, with lines of blue. The Tennessee so-called marble is mottled with chocolate and white.

Of foreign marbles, the best known are—the Brodliglio of Italy, in gray, shaded with black; the Sunna of Spain, a pale yellow; the Lisbon of Portugal, a pale reddish color; and the Belgian black of Belgium. Verde Antique is composed of bands of Serpentine and white marble.

The limestones are also of special interest in furnishing, by calcination, the several varieties of lime and cements.

Common Lime is obtained from the limestones of the middle and western States, from Maine and other States of New England; hydraulic lime is made in the State of New York; and many other localities furnish excellent lime or cement.

The limestones are indispensable to the iron-maker, also, as affording him an alkaline base, which, uniting chemically with the silica and alumina, and other impurities of the ores, allow the metal to separate in a state approximating purity; the silica and lime form the slag, which is also useful as a protecting covering over the molten iron, while it remains in the blast furnace. For such purposes a limestone free from magnsia or other impurity is generally most valuable.

Gypsum, Alabaster, or "Plaster of Paris" is a sulphate of lime, containing some water of crystallization. It takes the latter name from the fact that large deposits of this stone, of excellent quality, underlie the City of Paris and its environs.

When pure it contains, lime, 32.6; sulphuric acid, 46.5; water, 20.9. It is translucent and colorless. Its specific gravity is 2.6 to 2.8.

When raised to a high temperature, it loses its water of crystallization, and, if then finely powdered and made into a thin paste with water, it may be readily moulded and worked into any desired form. It then quickly "sets" or hardens. It is thus beautifully adapted for use in making casts and ornaments, and has recently been largely used in special branches of pattern making. It also makes an excellent cement for many purposes. The engineer uses it in making models and patterns, and for moulds which are not to be subjected to great heat.

This stone is found in many parts of our country. Considerable quantities are quarried in the State of New York.

Argillaceous Stones are of little value, as a rule, for the masons' work; they are generally weak, soft, and readily decomposed by the action of the weather.

Clay slate is a sedimentary, argillaceous rock, of fine-

grained, compact, and laminated structure, and is usually of dark shades of purple, blue, and green.

The best varieties of clay slate, or roofing slate, and of grauwacke-slate are used for roofing and flagging.

The former are obtained of remarkably fine quality in the State of Vermont; the latter, on the banks of the Hudson.

"**Fire-Stones**" are those capable of resisting the action of great heat, neither fusing, exfoliating, nor cracking.

Lime and magnesia, except where existing as silicates, are injurious in fire-stones.

Potash is very injurious, increasing the fusibility of the stone, and, melting, causing the formation of a fusible glass.

Quartz and mica, alone or in combination, make stones of great infusibility.

Mica-slate and gneiss are examples of excellent combinations, the latter, more particularly, when containing a considerable proportion of arenaceous quartz.

Limestones do not usually withstand the effect of heat well. The heat of the fire calcines it deeply where exposed, and thus destroys walls built of it. In the midst of great conflagrations, as at Chicago in 1871, the carbonic acid with which the lime is combined has been expelled so rapidly as to produce violent and explosive disruption. Magnesian limestones are little if any better than the pure limestones. Oleiferous limestones, containing silica and alumina, sometimes, however, resist fire moderately well.

Granite, gneiss, sienite, quartz, mica-slate, and other primary rocks usually contain some water; when exposed to fire, they crack and even explode. Walls constructed of these stones are apt to crumble rapidly in a hot fire.

Sandstones free from feldspar, somewhat porous and uncrystallized, are the most refractory of common building stones. Brick, especially when approximating to fire-brick in composition, is an excellent fire-resisting material, perhaps the best now known.

Concrete and béton, even when well made and completely set, and artificial stones consisting principally of silicates of

lime and alumina, are not generally very good heat-resisting materials.

Thin walls of any known building material will rapidly crumble in the midst of a large fire. The natural stones are less generally used where refractory materials are required, than are fire-brick, the characteristics of which latter will be described hereafter.

The Hardness of Stones is measured by comparison with some well-known stone of which the hardness is taken as a standard. The mineralogist's scale of hardness is the following, the softest being 1, and the hardest 10, on the scale.

HARDNESS OF MINERALS.

Diamond	10	Lapis lazuli	6
Ruby	9	Feldspar	6
Cymophane	8.5	Amphibole	5.5
Topaz	8	Phosphorite	5
Spinell	8	Fluor-spar	4
Emerald	8	Coclestine	3.5
Garnet	7.5	Barytes	3.5
Zircon	7	Carbonate of lime	3
Quartz	7	Mica	2.5
Tourmaline	7	Gypsum	2
Opal	6	Chlorite	1.5
Turquois	6	Talc	1

The comparative resistance of stones to abrasion is as follows* :

RESISTANCE OF STONES TO ABRASION.

Statuary marble	100.	Old Portland cement stone	79.
Bath stone	12.	Kilkenny black marble	110.
Stock brick	34.	Yorkshire paving stone	327.
Roman cement stone	69.	Aberdeen granite	980.

The Strength of Stone to resist Crushing varies

* *Journal Franklin Institute*, Oct., 1835.

immensely with different classes, and often very considerably even in the same class. Gen. Q. A. Gillmore has shown that under a maximum varying for each specimen, the resistance varies as the cube root of the length of the side of cubes experimented on. The densest stones are usually strongest.*

For Berea sandstone, Gilmore gives $y = a\sqrt[3]{x}$, in which y = crushing resistance per square inch of surface in pounds; x = the length of the side of the cube in inches, and a = from 7000 to 9500. (For metric measures: kilogrammes per square centimetre and centimetres, a = 350 to 500).

STRENGTH OF STONES UNDER COMPRESSION.

NAME.	KILOGRAMMES PER SQUARE METRE.	TONS PER SQ. FT.
Granite and sienite	7,655,000 to 10,936,000	700 to 1000
" " " good quality	9,842,000	900
Basalt and trap	8,749,000	800
Limestone and marble	3,827,500 to 7,655,000	350 to 700
Best sandstone, average	5,468,000	500
Conn. and New Jersey sandstone, ordinary	3,827,500	350
Slate	2,187,000 to 5,468,000	200 to 500

Trautwine takes the average weight of granite at 165 pounds per cubic foot (about 2643 kilogrammes per cubic metre), and of ordinary sandstone at 145 pounds per cubic foot (2323 kilogrammes per cubic metre), and calculates the height of column it would stand without crushing at the base as 8000 feet (2440 metres), and 4000 feet (1220 metres) respectively, for these two kinds of stone.

The weight imposed ordinarily on foundations of structures is rarely ten tons per square foot (109,360 kilogrammes per square metre). Stones of a soft quality usually begin to

* *Journal Franklin Institute*, Vol. LXV., p. 336.

crack at not far from one-half their crushing loads. The hardest stones yield suddenly and completely when the crushing load is reached. Stones crush most easily under soft materials, and offer most resistance between surfaces of hard steel. Polished stones resist better than rough.

Transverse Strength. — Experiments made upon building-stones by Mr. R. G. Hatfield are recorded in the Transactions of the American Society of Civil Engineers for 1872 *et seq.* The formula $W = S\frac{bd^2}{L}$ is used in expressing transverse strength. S = weight in pounds required to break a bar one inch square and one foot long between bearings; L = length in feet; b and d measure the breadth and depth of the sample in inches.

The coëfficient, S, varies from 250.76 to 227.19 for Hudson River blue-stone; for Kingston it is 203.50; for other specimens of blue-stone or grauwacke the coëfficient falls as low as 122.31. Marble from East Chester gives about 150. Sandstone from Belleville, New Jersey, gives coëfficients varying from 76 to 88.472; from Portland, Connecticut, 64.7 to 94; from Dorchester, Nova Scotia, 63 to 67. Ohio light sandstones give from 32 to 62.

For weights in kilogrammes, lengths in metres, and breadth and depth in centimetres, the values of S become eight one-thousandths those above given.

The *factor of safety* should never be less than ten, and a far higher value is adopted in practice by many experienced engineers. At the same time, it should be remembered that the crushing strength of the mortar or cement, used as the binding material, in many cases, rather than the strength of the stone itself, determines this limit.

The Durability of Stones varies as greatly as do their other qualities. It is determined by strength, hardness, and porosity. Experience and careful observation are the most reliable guides in judging of durability; but a series of carefully conducted tests may be made to yield valuable aid in estimating the values of newly opened quarries. In all important work a careful test should be made of the stone pro-

posed to be used. The quantity of water absorbed gives a good comparative test of the durability of stones of the same class, as does also their greater or less clearness of sound when struck with a hammer.

The following are the percentages of their own weight absorbed by different stones:

Granite absorbs from ½ per cent. to 1 per cent. of water.
Gneiss " " 1 " " " 2½ " " " "
Sandstone " " 1½ " " " 3 " " " "

Fine-grained stones absorb least water, and are usually hardest and best.

*M. Brard's method** of determining power of resisting the action of frost, is as follows: A cubical block, containing about 8 cubic inches (131 cubic centimetres), is sawn from a stone to be tested. This is suspended in a boiling supersaturated solution of sodic sulphate during a period of thirty minutes. It is then taken out, suspended above the liquid, and allowed to cool. This is repeated daily, or oftener, for at least a week. The crystallization of the salt within the pores of the stone disintegrates it, precisely as does the action of frost. The weights of the specimens tested are carefully taken before and after the test, and their comparative value is thus learned.

The chemical composition of stones greatly affects their durability. Potash is apt to wash out, leaving the stone soft and friable; clay absorbs water and thus softens stones of which it is a constituent; and iron, as has already been stated, injures by discoloration, and by the disintegration produced by changes from protoxide to peroxide.

Hatfield gives the following as the result of his examination of building-stones:

* Annales de Chimie et de Physique, vol. xxxviii.

DURABILITY OF STONES.

NO.	NAME.	LOCALITY.	WEIGHT PER CU. FT. POUNDS.	DURABILITY — YEARS REQUIRED TO DISINTEGRATE TO THE DEPTH OF $\frac{1}{10}$ INCH. (0.254 CM.)
1	Sandstone.....	Portland, Conn ..	150.41	2003.3
2	"	Berea, Ohio	134.14	2000.8
3	"	Marietta, Ohio...	161.94	1794.8
4	"	Dorchester, N. S.	140.52	811.40
5	"	Amherst, Ohio...	133.16	306.46
6	Coquina.....	Florida.....	105.76	6.92

Effect of Heat.—Expansion by heat takes place as follows, the range of temperature being 180° Fahr. (100° Cent.):

Granite and sienite 0008
Sandstone.....0006 to .0010.

Mr. H. A. Cutting, State Geologist of Maine, experimenting upon the granites, finds that their specific gravity varies from 2.50 to 2.83; that their power of absorption of moisture decreases irregularly with increase of density from 0.00300 to 0.00125, although the heaviest stones are not invariably least penetrable; that they are uninjured when heated to 500° F. (260° C.) and plunged into water, but that they are all injured at temperatures below the red heat; that at the latter temperatures they often crumble and become entirely worthless. The common sandstones vary in specific gravity from 2.2 to 2.6; they usually absorb from 0.06 to 0.25 water, although occasionally as little as 0.025, and withstand heat better than the granites, bearing temperatures 100° F. (55° C.) higher with equal safety.

The limestones examined compared favorably with the sandstones. Conglomerates are not equal to either of the former sorts. "Soapstone" withstands heat much better

than any other stone tested, receiving no apparent injury up to 1,200° F. (649° C.).

Artificial Stones comprise brick of various kinds, concrete, béton, and artificial imitations of sandstone.

Bricks are made by submitting clay, which has been prepared properly and moulded into shape, to a temperature which converts it into a semivitrified stone.

Common brick is a most valuable substitute for stone. Its comparative cheapness, the ease with which it is transported and handled, and the facility with which it is worked into structures of any desired form, are its valuable characteristics. It is, when properly made, nearly as strong as good building-stone; it is but slightly affected by change of temperature, or of humidity, is well cemented by mortars, and is also lighter than stone.

Common Clays, of which the common brick is made, consist principally of silicate of alumina; but they also usually contain, lime, magnesia, and oxide of iron. The latter is useful, improving the product by giving it hardness and strength; hence, the red brick of the Eastern States is often of better quality than the white and yellow brick made in the West. Silicate of lime renders the clay too fusible, and causes the bricks to soften and to become distorted in the process of burning. Carbonate of lime is certain to become decomposed in burning, and the caustic lime left behind absorbs moisture and promotes disintegration.

Uncombined silica is beneficial, if not in excess, as it preserves the form of the brick at high temperatures. In excess, it destroys cohesion, and renders the bricks brittle and weak. Twenty or twenty-five per cent. silica makes a good proportion.

Preparing the clay consists in clearing it carefully of pebbles, and after mixing it with about one-half its volume of water, "tempering" it either in a "pug-mill" or by hand stirring.

The clay is moulded into bricks by pressing it into forms, either by hand or by a machine, and they are then piled and burned, after having been well dried in the open air.

Burning occupies about two weeks. The bricks are first subjected to a moderate heat, until all remaining moisture has been expelled. The heat is then increased slowly, until, at the end of twenty-four hours, the "arch-bricks" attain a white heat; the temperature is then lowered somewhat, and a moderately high furnace heat is kept up until the burning is complete. Finally, all openings are closed, the fire is smothered, and the mass is then very slowly cooled.

In the more modern processes of burning brick the principal yards have permanent kilns built of brick, either circular or in the form of an ellipse, and made in compartments, each of which has a separate entrance and independent connection with the chimney. A down draught is secured from the top, where the fuel is placed, to the chimney, which is either built within the kilns or entirely outside, but which has its draught invariably connected with the bottom of the kilns. The fuel used is generally fine coal, which falls around the bricks, and the flame and heated gases surround and pass through all portions of the materials being burned. While some compartments are being burned, others are being filled, and still others are being emptied.

Bricks of three kinds are taken from the kiln. Those forming the top and sides of the "arches" in which the fire is built are overburned and partially vitrified. They are called "*arch-bricks*," are hard, brittle, and weak. Brick from the interior of the pile are called "*body-bricks*," and sometimes *hard* or *cherry brick;* they are of the best quality. Those brick which have formed the exterior of the mass are underburned, and are called *soft*, *sammel*, or *pale* brick. They are too soft, and are of insufficient strength for use, except for filling, in even ordinary work. Their price in the market is about twenty per cent. less than body brick, and variable.

Good Bricks should be of regular shape, with parallel surfaces, plane faces, and sharp edges and angles. They should exhibit a fine, compact, uniform texture, should be

quite hard, and should ring clearly when struck a sharp blow. They should absorb not more than six per cent. of their weight of water.

Brick of fair quality bears a compressive force of 3,000 pounds on the square inch (211 kilogrammes per square centimetre) without completely crushing.* Very soft bricks will yield at as low a pressure as one-eighth this amount; while the very best of pressed brick have been known to bear more than double 3,000 pounds.† Good brick may be taken to average about 2,000 pounds per square inch (141 kilogrammes per square centimetre.) Trautwine takes a minimum crushing strength for red brick at thirty tons per square foot (328,060 kilogrammes per square metre), and their weight at 112 pounds per cubic foot (1,794 kilogrammes per cubic metre) and thus estimates that a vertical column 600 feet (183 metres) high, would just crush at the base under its own weight. The experiments of Hatfield upon the transverse strength of brick gives a value for S in the formula $S = \frac{L\,W}{bd^2}$, of from 19.6 to 26.36 for Perth Amboy; of from 24.35 to 42.74 for Hudson River hard brick; and of from 32.29 to 41.85 for Philadelphia pressed brick. (In using metric measures, S becomes eight one-thousandths of these values as before.)

Masses of brickwork crush under smaller loads than single bricks; and first quality brick, laid in first quality cement, should not be subjected to much above ten tons per square foot (11 kilogrammes per square centimetre) as a permanent load.

The size and weight of bricks vary considerably. The British legal standard is $8\frac{3}{4} \times 4\frac{3}{8} \times 2\frac{3}{4}$ inches. In the United States, $8\frac{1}{2} \times 4 \times 2\frac{1}{4}$ is a usual size. Brickwork may be estimated at an average weight of 116 pounds per cubic foot. A good bricklayer lays from 100 to 200 bricks an hour, according to the character of the work.

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* G. S. Greene, *Journal Franklin Institute*, Vol. LXV., p. 332.

† The author has tested specimens capable of resisting more than 10,000 pounds per square inch, (703 kilogrammes per sq. cm.).

The following averages are given:

DESCRIPTION.	INCHES.	DESCRIPTION.	INCHES.
Baltimore front.....	$8\frac{1}{4} \times 4\frac{1}{8} \times 2\frac{1}{4}$	Maine.....	$7\frac{1}{2} \times 3\frac{5}{8} \times 2\frac{5}{8}$
Philadelphia "		Milwaukee.....	$8\frac{1}{2} \times 4\frac{1}{2} \times 2\frac{1}{2}$
Wilmington "	.. .. ..	North River.....	$8 \times 3\frac{1}{4} \times 2\frac{1}{4}$
Croton "	$8\frac{1}{4} \times 4 \times 2\frac{1}{4}$	Ordinary	$7\frac{1}{4} \times 3\frac{5}{8} \times 2\frac{1}{4}$
Colabaugh.....	$8\frac{1}{4} \times 3\frac{3}{8} \times 2\frac{5}{8}$		$8 \times 4\frac{1}{2} \times 2\frac{1}{2}$
Stourbridge fire-brick.....			$9\frac{1}{2} \times 4\frac{5}{8} \times 2\frac{5}{8}$ inches.
American (N. Y.).....			$8\frac{7}{8} \times 4\frac{1}{4} \times 2\frac{3}{8}$ "

Fire-brick is used whenever very high temperatures are to be resisted. They are made either of a very nearly pure clay—silicate of alumina—of a mixture of pure clay with clean sand, or, in rare cases, of nearly pure silica cemented with a small proportion of clay. The presence of oxide of iron is very injurious, and it has been accepted as a rule by good engineers, that the presence of six per cent. ferric oxide in the brick justifies its rejection. It should generally be stipulated that fire-brick proposed for purchase should contain less than six per cent. of oxide of iron, and less than an aggregate of three per cent. of combined lime, soda, potash, and magnesia. The sulphide of iron—pyrites—is even worse in its effect on fire-brick than the substances just named.

Where intended to resist extremely high heat simply, silica should be in excess; and where exposed to the action of metallic oxides, which would tend to unite with silica, alumina should be in excess.

Good fire-brick should be uniform in size, regular in shape, homogeneous in texture and composition, easily cut, strong and infusible. A good bricklayer should lay sixty per hour.

The strength of fire-brick, as determined by experiments at the Royal (British) Arsenal, in 1871, is sufficient to enable it to sustain from 900 up to 2,000 pounds per square inch (63 to 141 kilogrammes per square centimetre) before crushing. Bricks tested by the author have usually borne the maximum figure and often exceed it two or three times.

Excellent fire-brick is made at Newark, South Amboy, and other places in New Jersey. The most infusible known fire-bricks are the Welsh Dinas bricks, which consist of 97 per cent. silica and 3 per cent. alumina and other constituents. The Mount Savage brick, of Maryland, U. S., is also noted for its infusibility.

In lead smelting furnaces preference is given to fire-brick made of kaolinitic clay.

Retorts for gas manufacturers, for glass-makers, and for other purposes, are made of fire-clay, in a similar manner to fire-brick, but they necessarily require more care in selecting materials, in moulding, and, particularly, in baking.

A celebrated fire-clay has the following composition:

SAMPLE.	SILICA.	ALUMINA.	PROT. IRON.	LIME.	MAGNESIA.	POTASH.
Sample 1.....	59.87	33.49	3.01	1.42	0.31	2.21
Sample 2.....	67.69	27.91	2.35	0.63	0.11	....
Sample 3.....	70.32	26.42	1.04	0.36	0.43	1.40

It makes excellent fire-bricks and crucibles, burns perfectly white, and makes a fine glass-house clay.

Artificial Sandstones are made by several processes. Of these béton and concrete will be referred to after explaining the methods of making mortars and cements.

Mortars and Cements are used in masonry for the purpose of uniting the natural and artificial stones. They usually, when completely hardened or "set," consist wholly or partially of carbonate of lime united with sand, or with sand and clay. Plaster of Paris—sulphate of lime—is also sometimes used. Carbonate of lime is formed by the absorption of carbonic acid from the atmosphere, which unites with the lime with which the mortars and cements were originally made up.

In the structures of the ancient Egyptians, as in the Great Pyramid, mortar was freely employed; but it consisted almost entirely of sulphate of lime. A specimen taken from an ancient Phœnician temple, the highest stone of which was,

a few years ago, five feet below the level of the ground, was quite similar to that found in some of the castles in Europe, and was like a piece of solid rock. It was made of burnt lime, fine sand, coarse sand, and gravel. It was a concrete rather than a mortar; the lime had become completely carbonated. Ancient Greek mortars from ruins in the neighborhood of Athens are in very perfect condition; they contain no gravel. Mortars from ruined buildings in Herculaneum, and from Rome and its vicinity, appear to have been made from burnt lime and puzzolana, or volcanic ash.

Lime, as a building material, is of three principal kinds: *common or air lime, hydraulic lime, and hydraulic or water cement.*

Common lime, called also pure, rich, or fat lime, is produced by calcining limestone, which is nearly pure carbonate of lime, and thus expelling its carbonic acid.

It "slakes" by greedily absorbing moisture, becoming converted into a dry hydrate, if water is not used to excess. Made into a paste with water, it hardens slowly in the air, but not at all under water.

Hydraulic Limes are made from stones containing from 18 to 30 per cent. of silicate of alumina, of carbonate of magnesia, or of a mixture of both. They slake more slowly than air lime, and the paste hardens very slowly under water, or in wet localities.

Hydraulic cements are made by calcining limestones containing from 30 to 60 per cent. of clay. They do not slake, and their pastes harden with rapidity under water. They are, therefore, of greatest use in building foundations. Where the proportion of silicate of alumina is greater than 60 per cent., the material is called *puzzolana,* and it requires the addition of fat lime to render it useful. Natural puzzolana is of volcanic origin. Brick-dust has a similar power of rendering fat limes hydraulic, as has also trass, terras, or blue trap-rock.

The hydraulic limes and cements are sometimes obtained from stones which contain the desired proportion of limestone and clay; in which case they are known as ***natural***

limes or cements. Sometimes the lime and the clay are mixed artificially in proper proportions.

Limestones of all qualities are found in New England, New York, and many other portions of the United States.

The English Portland cement is made by grinding together chalk and clay. That from the gray chalk is said to be heaviest and best. This is the strongest cement known in the market, and it is by far the most expensive.

Roman cement is made from nodules of limestone containing clay and iron. It makes a cement which sets more quickly than the Portland, but does not become as hard.

Mortars are made by mixing lime and sand with water in such proportions as will give the desired quality, thus forming a paste which may be used for uniting stone and brickwork.

Common Mortar is made with fat lime, and clean, sharp sands, in the proportions, usually, of 1 to 5 by volume.

It hardens promptly in the air, and becomes, finally, very hard, if of good quality, and if frost, or too great dryness, or excessive dampness does not injure it while setting.

Hydraulic mortar is made with hydraulic lime and sand. It hardens in damp situations, and is a strong binding material. Under water it often requires weeks to harden; but hydraulic mortar of fair quality requires from three or four days to a week. Very excellent varieties harden in from one to four days. It is often tempered with clay or lime to retard its setting. The slower this action, usually, the firmer and harder does the mortar finally become.

Hydraulic cement is a mortar made with the very hydraulic lime, also termed cement, already described. Hydraulic cements sometimes set in a few minutes after mixture, if warm; they do not shrink much in setting, and are often used without admixture of other material. Where even slight shrinkage is objectionable, an addition of three times its own volume of sand will prevent change of volume. Hydraulic cement is generally indispensable in the construction of foundations. It should be laid in thin joints, and should generally, if great strength is desired, be used un-

mixed with sand; it requires about one-third its volume of water.

The sand used in mixing mortars should be free from clay and perfectly clean; it should be sharp and rather coarse. River sand is usually found to be better than sea sand, as it is free from salt, and is less liable to be found water worn.

Mortars and cements are given different proportions for different kinds of work. Mortar for stone may be made by mixing 15 to 20 per cent. cement, 6 to 8 parts lime, and the remainder of the 100 parts sand; mortar of good quality for brickwork should contain 10 per cent. less sand. Stucco is made of two parts sand to one part cement; to this is sometimes added a little sugar or molasses.

Plaster for inside finish is usually of several grades. Coarse plaster is made by adding to common mortar about five per cent. of its volume of cows' hair; "fine stuff," or putty, is a paste of lime mixed without sand; "hard-finish" contains of lime 3 or 4 volumes, of plaster of Paris 1 part.

Concrete is made by mixing gravel or broken stone with lime and sand, using a limited amount of water. Fragments of brick are often also added.

It is mixed in about the proportion of 1 part lime, by volume; 6 parts or more of sand and other solid components, and 1½ parts water. In using it, it should be thoroughly mixed and carefully rammed in place. It swells about three per cent. in setting. Each cubic foot (.028 cubic metre) of gravel makes about four-fifths of a cubic foot (.022 cubic metre) of well rammed concrete.

Used as a foundation for masonry, it should be laid in layers of about a foot in thickness, each being carefully rammed before another is added. It is not well fitted for use in damp localities.

Béton is the name usually applied by engineers to a concrete in which hydraulic lime or cement is used, instead of fat lime. It should always be given the preference in wet, or even in damp, situations; and is often used on dry work also, when strength is sought.

Occasionally a little lime is added to retard the setting of strong hydraulic cement concrete.

A commission reporting on the submarine work of the New York Dock Commission states that in order to produce good submarine masonry by depositing freshly mixed concrete under water, certain precautions are necessary, viz.:

The cementing material should possess the properties of unctuousness and adhesiveness, to enable it to retain the sand while the concrete is assuming a state of rest in the water; and it should be capable, as much as possible, of assuming that state by spreading, rather than by breaking down and rolling off on the sides of the mass deposited.

If it be deficient in the properties last named, it should then be quick-setting, in order that the washing out of the sand from the cement may be arrested in a few minutes after deposition by its prompt hardening.

If a box is used for depositing the concrete, the shape of the box, and the method of emptying it, should be such that the concrete will be subjected to as little wash as possible. Hence a large box is preferable to a small one, as it will expose a less area of surface in proportion to the volume deposited.

Béton has been used in the following proportions on the works named, with excellent results:

Croton Aqueduct, New York—New York cement, 1 part, by volume; sand, 3 parts; broken stone, small enough to pass through a ring 1½ inches (3.8 centimetres) in internal diameter, 3 parts;—Cherbourg Breakwater, France—Portland cement, 1 part; sand, 3 parts.

Properly made, this concrete, or béton, is found to be strong enough to take the place of stone; walls, chimneys, and even bridges have been constructed of it.

The addition of a small quantity of sulphuric acid, or the presence of a sulphate, is found to add very considerably to the strength of mortars.

Béton-Coignet, as made by the French engineer, M. F. Coignet, and which attracted much attention at the International Exposition at Paris, in 1867, is composed of: lime, 4 parts; hydraulic cement, 1 to 2 parts; and sand, 20 parts.

The ingredients are first thoroughly intermixed dry, by hand, and again in a mill, moistening them very slightly with clean water. Moulds are then filled with the mixture, and it is compacted by ramming or hammering

Four bushels of the mixture, occupying, when dry, five cubic feet (141.6 litres), make three cubic feet (85 litres) of finished work, weighing 140 pounds per cubic foot (2,243 kilogrammes per cubic metre). Its peculiarities are the small quantity of water used in its manufacture, and the thoroughness with which the mixing and ramming are done. It sets quickly, is very strong, and is the best example of mixed béton.

It may be made into blocks to be used as cut stone, or may be built up in masses of any desired shape. The cheapness and strength of construction of Béton-Coignet are so remarkable as to have led to its use for even ornamental work. It is used to a considerable extent in constructing the walls of houses and public buildings.

Strength of Mortars, Cements, and Concrete.—Mortar has a tenacity of from 6 to 34 pounds per square inch (0.42 to 2.39 kilogrammes per square centimetre) when six months old; and the average, as determined by General Totten, U. S. A., was about 15 pounds per square inch (1.05 kilogrammes per square centimetre), or nearly a ton per square foot (10,937 kilogrammes per square metre).

The increase in strength, with age, is very variable, amounting sometimes to twice or three times these figures, and, at other times, to a mere fraction.

The resistance to crushing, a year and a half after setting, is given by Rondelet as from 440 to 580 pounds per square inch (31 to 41 kilogrammes per square centimetre) when simply laid in place; and from 600 to 800 pounds (42 to 56 kilogrammes) when well rammed. These figures correspond to about 30 and 35, 40 and 50 tons, respectively, to the square foot (328,066 and 382,750, 437,450 and 546,800 kilogrammes per square metre).

Its adhesion to brick or stone work is about equal to its cohesive strength, on good work, of moderate age; if very old, the adhesion is greater.

Gypsum is used in taking casts, and in stereotyping. Gypsum is also employed for glazing porcelain, and, being an excellent non-conductor of heat, with alum for filling fire-proof safes. Made into a mortar with sand and lime, it is used for cementing floors and vaults.

The best gypsum quarries that are worked on this continent are those of the Bay of Fundy, Nova Scotia, and Hillsboro, New Brunswick. Over one hundred thousand tons of the finest quality have been annually imported from these places into the United States.

The Bituminous Cements are usually composed of mixtures of bituminous substances, as asphalt, with less costly materials. Bitumen or mineral tar, asphalt, and a bituminous limestone are thus used. The latter sometimes contains ten or fifteen per cent. bitumen.

The mixtures are made by breaking up the materials, and heating them in large iron kettles or boilers. The proportions in mastic are usually from one to one and a half parts bitumen to each ten of asphalt.

Coal-tar, although of far inferior value, is frequently used instead of the natural bitumen, as is also pitch.

Fire-clay is sometimes used in place of limestone, and the preparation so made makes excellent joints for water-pipes.

Bituminous cements mixed with broken stone to form a bituminous concrete sometimes make a good road covering.

Masonry is the art of making structures of stone, brick, or other earthy materials.

Good masonry is built in "courses," which are usually perpendicular to the lines of pressure bearing upon them, with discontinuous or "broken" joints in the lines of stress. The stone-mason selects the heaviest stones for his lowest courses in all foundations or structures, lays all stones on their natural beds, and secures the most perfect union between them and the cementing material.

The nomenclature of stone masonry has been revised by a committee of the American Society of Civil Engineers,* and

* Trans., No. CLI, 1877.

the specifications of the engineer are recommended to be made in accordance with their report and as below.

Stones are classed thus:

In practice, one class merges into the next.

I. *Unsquared Stones or Rubble.*—This class includes stones used as they come from the quarry, without other preparation than the removal of sharp angles and projections. The term "backing," frequently applied to this class of stone, properly designates material used in certain relative positions in the wall; while stones of this kind may be used in any position.

II. *Squared Stones.*—This class includes stones roughly squared and dressed on beds and joints. The dressing is done with the face hammer or the axe, or, in soft stones, with the tooth hammer. On gneiss, the point is sometimes used. Where the dressing on the joints is such that the average distance between the surfaces of adjoining stones is one-half inch or more, they properly belong to this class.

Three subdivisions of this class may be made, depending on the character of the face of the stone.

(*a.*) Quarry-faced stones are left untouched as they come from the quarry.

(*b.*) Pitch-faced stones have the arris clearly defined by a line beyond which the rock is cut away so as to produce edges approximately true.

(*c.*) Drafted stones have the face surrounded by a chisel draft, the space inside the draft being left rough. Ordinarily this is done only on stones in which the cutting of the joints is such as to exclude them from this class.

In ordering stones the specifications should state the width of bed and end joints, and how far the surface of the face may project beyond the plane of the edge. In practice the projection varies between 1″ and 6″. It should be specified whether the faces are to be drafted.

III. *Cut Stones.*—This class includes all squared stones with smoothly dressed beds and joints. As a rule, all the edges of cut stones are drafted, and between the drafts the stone is smoothly dressed. The face, however, is often left rough, when the constructions are massive.

The following are usual methods of dressing stones:

Rough-Pointed.—When necessary to remove an inch or more from the face of a stone, it is done by the pick until the projections vary from ½″ to 1″. The stone is then said to be rough pointed. This is the first operation in dressing limestone and granite (Fig. 112).

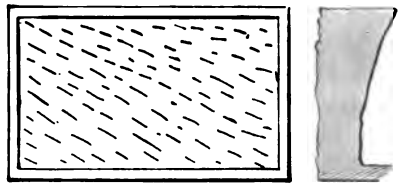

FIG. 112.

Fine-Pointed.—When a smoother finish is demanded, rough pointing is followed by fine pointing (Fig. 113). It is used where the finish is to be final, and not as a preparation for final finish by other tools.

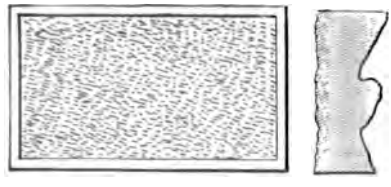

FIG. 113.

Crandalled.—This is a rapid method of pointing, the effect is the same as fine pointing, except that the marks on the stone are more regular. The variations of level are about ⅛″, and the rows are parallel. When other rows, at right angles to the first, are introduced, the stone is said to be *cross-crandalled* (Fig. 114).

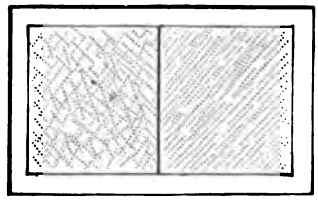

FIG. 114.

Axed or Pean Hammered, and Patent Hammered.—These vary only in the degree of smoothness of the surface (Fig. 115).

The number of blades in a patent hammer varies from 6 to 12 to the inch, and in specifications the number of cuts to the inch is stated, such as 6-cut, 8-cut, 10-cut, 12-cut. The effect of axeing is to cover the surface with chisel marks which are made parallel as far as practicable. Axeing is a final finish.

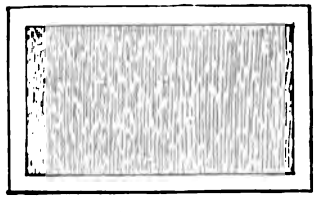

FIG. 115.

Tooth-Axed.—The tooth-axe is practically a number of

points and it leaves the surface of a stone in the same condition as fine pointing. It is usually a preparation for bush hammering, and the work is then done without regard to effect, provided the surface of the stone is sufficiently levelled.

Bush Hammered.—The inequalities of a stone are pounded off by the bush hammer, and the stone is then said to be "bushed" (Fig. 116). Sandstone thus treated is very apt to scale.

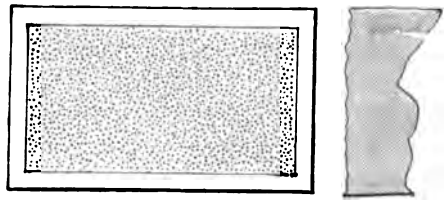

FIG. 116.

In dressing limestone which is to have a bush-hammered finish, the usual order of operations is: 1st, rough pointing; 2d, tooth axeing; 3d, bush hammering.

Rubbed.—In dressing sandstone and marble, it is very common to give the stone its surface at once by the use of the stone saw. Any inequalities left by the saw are removed by rubbing with grit or sandstone. These stones are used in architecture for string courses, lintels, door jambs, etc., and are well adapted for use in localities where a stone surface is liable to be rubbed by vessels or other moving bodies.

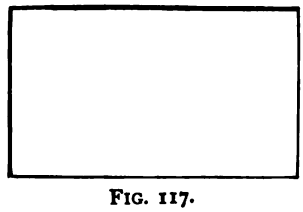

FIG. 117.

Diamond Panels.—The space between the margins is sunk immediately adjoining them, and thence rise the four planes forming an apex at the middle of the panel; this makes a sunk diamond panel. When the surface of the stone rises gradually from the inner lines of the margins to the middle of the panel, it is called a raised diamond panel (Fig. 118).

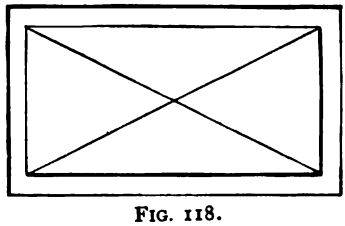

FIG. 118.

The term stone masonry includes:

(1.) *Rubble Masonry* is composed of unsquared stones; it may be Uncoursed Rubble (Fig. 119), laid in irregular courses,

or Coursed Rubble (Fig. 120), levelled off at specified heights, The stone may be required to be roughly shaped with the hammer, so as to fit fairly.

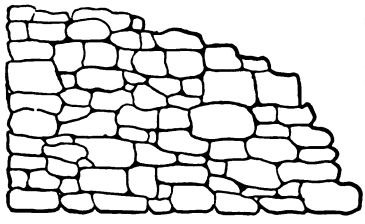

FIG. 119.

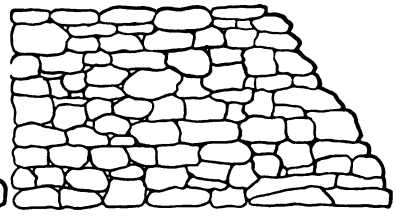

FIG. 120.

(2.) *Squared Stone Masonry.*—This is classified as Quarry-faced (Fig. 121), or as Pitch-faced (Fig. 122). If laid in regular

FIG. 121.

FIG. 122.

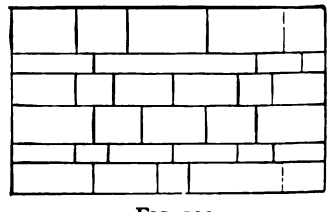

FIG. 123.

courses, it is Range work (Fig. 123). If laid in courses that are not continuous throughout the length of the wall, it is Broken Range work (Fig. 124). If not laid in courses, it is Random

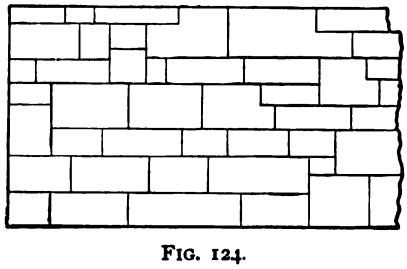

FIG. 124.

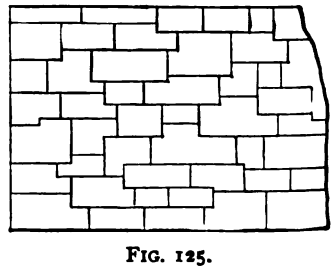

FIG. 125.

work (Fig. 125), and this is generally the method adopted.

In quarry-faced and pitch-faced masonry, quoins and the sides of openings are hammer-dressed, in removing projections to secure a rough-smooth surface, with the face hammer, the

plain axe, or the tooth axe. This is done for doors or window-frames, and improves the general effect if used where a corner is turned.

(3.) *Ashlar Masonry.*—This is "cut-stone masonry," or masonry composed of any of the kinds of cut stone. The courses are continuous (Fig. 126), but sometimes are broken

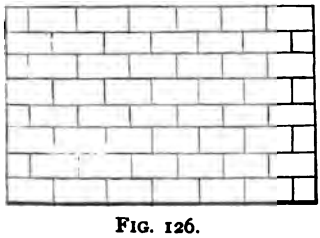

FIG. 126.

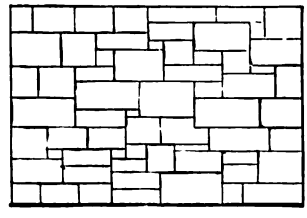

FIG. 127.

by the introduction of smaller stones; it is called Broken Ashlar (Fig. 127). If the stones are less than one foot in height, the term Small Ashlar is proper. The term Rough Ashlar is sometimes given to squared stone masonry when laid as Range work; but it is better to call such masonry "Squared Range work."

Dimension stones are cut stones, whose dimensions have been fixed. Specifications for Ashlar masonry prescribe the dimensions to be used.

General Rules.—Range work is usually backed up with Rubble masonry, which is specified as coursed Rubble.

Every specification should contain an accurate description of the character and quality of the work desired. Samples of cutting and masonry should be prepared beforehand.

The softer stones should have a depth equal to at least one-third their length to prevent crossbreaking, and a breadth of one-half their length. The hard and strong stones are allowed a double length. A rough natural surface is of advantage when strong adhesion of mortar is important. The thickness of joints in Ashlar masonry is about ⅛ inch, and in fine work as little as can be secured. All spaces should be completely filled. In coursed masonry one-fourth or more of all stones should be headers, *i. e.*, should extend from front to back, and the re-

mainder are stretchers, *i. e.*, lie lengthwise in the wall. Common Rubble has about the strength of mortar; coursed and fine work has nearly the strength of the stone itself. Ashlar is usually backed with Rubble, and both should be carried up together, and, as nearly as possible, the whole length of wall should rise together. The top of the wall is protected by its *cope*, which is a "string-course," *i. e.*, a projecting course; and is made of stones long and broad enough to protect the wall from rain, and heavy enough to be displaced with difficulty; they should be of good shape to shed rain. Adjacent stones in the coping, and in engine and in lighthouse foundations, or other places in which great strength is demanded, are secured together by iron "cramps" or "dowels" of metal or stone.

The joints of masonry are finished on the surface by "pointing" with cement, plaster, or fine mortar, to give smoothness of surface and to cause them to shed rain.

In the Measurement of Masonry, stone-work is measured by taking openings less than 3 feet (0.9 metres) wide as solid wall, and adding 18 inches (0.45 metres) for each jamb. Arches are usually taken as if solid from the springing line; corners are measured twice, and pillars are measured by the area of three sides multiplied by the fourth. Foundations and dimension stones are measured by cubic measure; water-tables and base courses in lineal feet, and sills and lintels in superficial feet.

Brickwork is laid like stone-work, with the line of courses perpendicular to that of pressure. Broken and soft bricks are rejected, and each brick laid should be wetted and cleaned before laying it in place; the joints should be as thin as $\frac{1}{4}$ or $\frac{3}{16}$ inch (0.64 to 0.48 centimetres). About one-fifth as much mortar as brick is generally used. The "English bond," in which entire courses of stretchers and headers are laid at regular intervals as the wall rises, is considered strongest; when laid one course of headers to each two courses of stretchers, the strength is very nearly the same lengthwise and crosswise. "Flemish bond" is laid header and stretcher alternating in each course; it is easier to retain regularity in breaking joints

in this bond, but it lacks strength and is not as neat in appearance as English bond.

Brickwork is measured by the thousand bricks; with average sizes and good work, the following are the number of bricks laid by the superficial foot:

4-inch	(10.16	centimetres)	wall....	7	to sq.	ft.,	75	to square	metre.
9	"	(22.36	"	)	"	...14	"	150	"	"
13	"	(33.02	"	)	"	...21	"	216	"	"
18	"	(45.72	"	)	"	...28	"	300	"	"
22	"	(55.88	"	)	"	...35	"	377	"	"

Corners are measured twice; small openings are taken as solid work; arches are measured as solid from the springing line, and pillars are measured on the face.

Masonry will carry safely from 2 to 10 tons per square foot (21,875 to 109,379 kilogrammes per square metre), according to quality; and carefully built masses of cut and dressed granite may carry four times the higher figure.

Masonry in damp situations is always laid in hydraulic mortar or cement, and the lower courses of walls and foundations are usually carried below the frost-line. The soil should be carefully drained. Where new masonry abuts upon old work, there is always danger of cracking by the settling of the new work; but every precaution should be taken to secure a good bond between the two portions and to make the joints of the new work thin, and of cementing material of such consistency as will prevent excessive shrinkage.

The Cost of Masonry cannot be given except on the assumption of a fixed rate of wages. Taking the wages of a laborer at $2.00 per day, and for the mason $4.00, we may reckon as below.

Where wages fluctuate, and, indeed, in all cases, if possible, a careful estimate should be made after ascertaining the conditions actually affecting prices. In the estimate below stones are assumed of moderately large size. Smaller stones cost less to handle, but more for dressing.

Rubble masonry should cost probably one-half these figures if of good quality, and may fall to one-fourth when the stones used are small.

COST OF MASONRY; ASHLAR.

Quarrying 1¼ cubic yards	$4 00	
Dressing 16 sq. ft. face @ 40c.	6 40	
Dressing 48 sq. ft. joint @ 20c.	9 60	
Cost of stone per yard		$20 00
Haulage, variable, say	2 50	
Mortar	1 00	
Laying one cubic yard and incidentals	2 50	
Cost of placing		6 00
Contractor's profit, 15 per cent		4 00
Total cost		$30 00

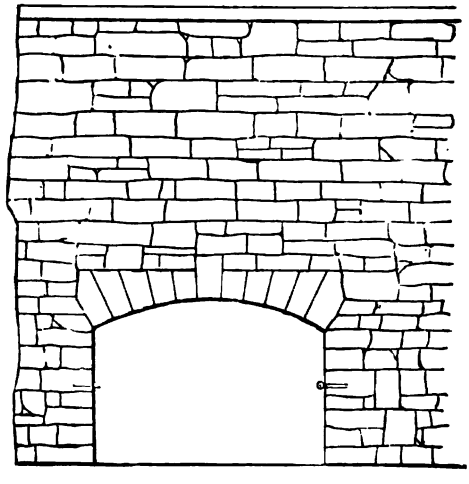

FIG. 128.—COURSED RUBBLE WALL.

CHAPTER XIX.

TIMBER.

"**Timber**" is that portion of the woody material of trees which is used in carpentry and joinery. Hence the term only applies to the wood of particular kinds of trees, which are therefore designated as "timber-trees." In some districts of the United States, timber cut and dressed is distinctively called "lumber," the term timber being restricted to the standing wood.

The timber-trees are nearly all of those classes known by the botanists as *exogenous, i. e.*, those in which growth takes place by the formation of woody fibre on the external surface of the sap-wood, immediately beneath the bark.

Endogenous trees, as those of the palm family, do not furnish timber. Their growth takes place by an internal formation of ligneous fibre, and the wood is not firm and solid enough for the purposes of carpentry.

If the trunks of timber-bearing trees are cut, they are found to be composed of concentric cylindrical layers, whose cross sections form rings, separated from each other, and evidently quite distinct. These layers are formed, one each year, during the period of growth of the tree. They vary in thickness, in density, and in color, according to the rapidity of growth, the length of the season, and other circumstances which may change from year to year.

The outer portion of the trunk is called the "*sap-wood*," and is usually lighter in color, and less strong and dense than the interior portions, or *heart-wood*.

The circulation of the sap through the sap-wood occurs during favorable weather. In winter it is supposed to cease, and this period of checked circulation causes the line of demarkation between successive annual rings.

In midsummer also, in our climate, and in the height of the dry season in tropical climates, the sap flows less freely than either earlier or later in the season. During the month of July, with us, it almost ceases flowing.

The heart-wood is nearly, or quite, impervious to sap, its vessels being closed up, and the wood is dense and hard. It is almost pure woody fibre, is free from sap, and contains almost none of the sugar and the mucilage which are found in sap-wood. It is usually far more durable therefore than the latter. Different kinds of trees, and different individuals of the same species, have different proportions of sap-wood. The slower-growing trees usually contain least.

The complete conversion of sap-wood into heart-wood occupies from one year, as with the softer woods like beech, to twenty or thirty years, and even longer, as with the oak. In the first class, slow growth, and in the second, a comparatively rapid growth, produces the best wood.

Decandolle gives the following as the maximum age of timber-trees, the figures being obtained by counting the annual rings of old trees: Elm, 335 years; cypress, 350; larch, 575; cedar, 800; linden, 1,150; oak, 1,500; and the adansonia, 5,000.

The longevity of various trees has been stated by others to be, in round numbers, as follows: Baobab tree of Senegal, 5,000 years; dragon's-blood tree, 4,000; yew, 3,000; cedar of Lebanon, 3,000; olive, 2,500; oak, 1,600; orange, 1,500; oriental plane, 1,200; cabbage palm, 700; lime, 600; ivy, 600; ash, 400; cocoa-nut palm, 300; pear, 300; apple, 200 years. These estimates are disputed, however, and are by some writers thought greatly in excess of the correct figures, as it is found that several rings may be sometimes formed in a single year.

The length of the life of trees seems largely dependent upon the proportion of heart-wood, and, particularly, upon its durability, decay usually originating and progressing, in growing trees, only in the heart-wood. The sap-wood and bark are peculiarly subject to the attacks of worms and insects. At the period of maturity the heart-wood is of maximum density and uniformity of texture.

"Felling" Timber should always, if possible, be practised at the period of maturity; if earlier, the wood will not have acquired its greatest strength and density, and will contain too great a proportion of sap-wood; if later, the wood will have become weakened by incipient decay.

The oak is said to reach maturity when about 100 years of age, and it should not be felled at less than 60.

Pine timber should be cut at from 70 to 100 years of age, and ash and elm at from 50 to 100.

The season of the year best adapted for felling timber is either midwinter or midsummer. The months of July and August are often selected, as at those seasons the sound trees remain green, while the unsound trees are then turning yellow. Healthy trees then have tops in full foliage, and the bark is uniform in color, while unsound trees are irregularly covered with leaves of varying color, having a rougher, and often a loosened, bark, and decaying limbs.

The cut should be made low, and the opposite incisions should be so made, especially with oak, as to enable the trunk to be cut clear of the stump while falling; otherwise the trunk may be split. The trunk should be immediately stripped of its bark, and, when heart-wood only is wanted, the sap-wood removed as soon as possible. The bark is often removed from trees in spring, and the felling deferred until autumn or winter. This is probably the best course to pursue, usually.

Handspikes and similar "uses" should be cut from young straight trees, and near the butt.

Seasoning Timber is simply driving out the sap from its pores by either natural or artificial means. This should always be done as gradually as possible, otherwise the timber is liable to crack or "check," from irregular drying.

Natural or air seasoning gives the best results. The timber should in all cases be squared as soon as cut, and all large logs should be halved, or even quartered. It is then piled in the seasoning yard in such a manner as to be protected as far as possible from the sun and rain. It should be placed where the air may circulate freely on all sides, not only of the pile, but of each log; bad ventilation is sure to cause rot. After

remaining thus for some months, the logs may be cut into smaller joists, if needed in such form, or into planks and boards, and again piled for further seasoning. For heavy work, two years, and for lighter work, four years, is sufficient time for seasoning boards; but timber is rarely overseasoned.

The loss of moisture in the first year of seasoning may be taken usually as about twenty per cent. When piled for seasoning in air, the lower sticks should be placed on supports one to two feet high, to keep them from contact with the damp earth. At least an inch should separate adjacent pieces. The timber should be repiled often enough to secure the detection and removal of unsound pieces.

Water seasoning is accomplished by immersion in water for a long time. It is a slow and imperfect method, but for timber to be used in water, or in damp situations, it answers well. The sap, in this case, is removed by solution.

In salt water there is usually some danger that the wood may be attacked by the ship-worm, *Teredo navalis*, or by the *Limnoria terebrans*, both of which destroy timber very rapidly. It should therefore be carefully watched. Two or three weeks water seasoning is sometimes found to be a good preparation for air seasoning, by dissolving out the more soluble salts contained in the wood.

Steaming timber is resorted to where it becomes necessary to soften wood, in large pieces, for the purpose of bending it, as in ship-building. An hour to each inch of thickness is the period of time allowed. This process sometimes impairs the strength; but it is also a seasoning process, and preserves from decay as well as from injury by warping or cracking.

Hot-air seasoning is resorted to where it becomes necessary to season wood rapidly. The timber is piled in large chambers or ovens. The sap is expelled by a current of hot air, having a temperature of from 100° Fahr. (38° Cent.), with large logs of hard wood, to 250° to 300° Fahr. (121° to 149° Cent.), with thin boards of the softer kinds, the wood losing, in the latter class of materials, about thirty per cent. of its weight.

The time required may be stated to be generally one week

for each inch (2.54 centimetres) of least thickness, to insure good work.

In seasoning birch sticks, one inch or one and a quarter inch (3.2 centimetres) square, sixty hours are allowed.

The fuel used amounts to about ten per cent. of the weight of seasoned wood.

Seasoning by passing the smoke-laden products of combustion from the furnace, directly through the pile of timber, has been found not only a good method of seasoning, but also to have an important and useful preservative effect.

Seasoning by boiling in oil is resorted to for some purposes, as the preparation of hickory for use in making teeth of mortice gears. If carelessly done, the wood may be seriously injured by the charring of its fibre in the overheated liquid; but if the temperature is carefully kept at, or somewhat under, 250° Fahr., the result will be most satisfactory.

The wood should be seasoned in blocks roughed out to nearly the finishing size, and they become not only well and uniformly seasoned, but, as shown by the experiments of Mr. G. H. Corliss, considerably strengthened.

If well done, seasoning usually increases the strength of timber, but the amount of this increase is very variable. Pine gains about ten per cent., elm from ten to fifteen, oak from five to twenty-five, and ash and beech often gain forty per cent. or more.

The amount of water contained in green timber varies from twenty-five or thirty per cent., in willow and ash, to thirty-five per cent. in oak, and forty per cent. in pine.

Large beams are best built up of small pieces, in order to secure thorough seasoning, and to avoid risk of decay.

Shrinkage always occurs to a greater or less extent, in consequence of the expulsion of moisture while seasoning; and some woods not only shrink, but warp badly, while others are seriously injured by the occurrence of "seasoning cracks."

The shrinkage of timber is not usually very noticeable in the direction of its length; but transverse shrinkage often occurs to a marked degree. In soft timber, as birch, it amounts to about eight per cent.

The tree consists of a bundle of capillary tubes, cohering laterally, the sap-wood, when green, filled with sap, and having the heart-wood moist, but choked with resinous matter.

These fibrous bundles, or the *vascular tissue*, are bound together by a *cellular tissue*, the membrane which constitutes the medullary rays, which latter form, in many woods, as in oak, well-marked dividing planes and lines of weakness; they consequently determine the surfaces along which season cracks may be developed while shrinking. The inner portion of the tree, the heart-wood, being denser and less fully saturated with moisture than the external or sap-wood, shrinks less, and thus it happens that all planks, composed of portions of both kinds of wood, or of different qualities of the same kind, are certain to be warped or otherwise distorted while seasoning.

Usually a log is cut into planks, when green, by gang or circular saws, and these planks, originally of the shape seen in Fig. 129, are likely, when seasoned, to take the shapes seen in Fig. 130.

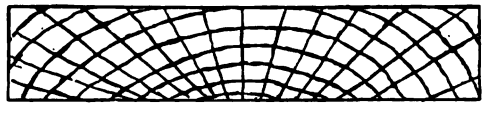

FIG. 129.

The shrinkage warps the outer planks and distorts the middle one, by reducing its thickness to a greater extent at the edges than in the middle. The simple inspection of the position of the medullary rays and annual rings in a piece of green wood will enable any one to determine from what part of the trunk it has come, and to predict its change of form while seasoning.

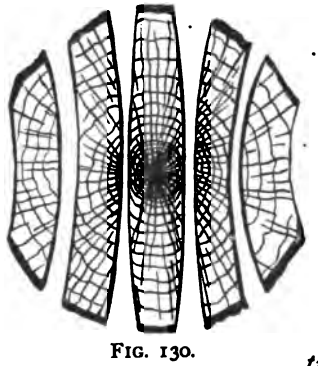

FIG. 130.

Nomenclature.—The term *timber* is seldom applied, in the trade, to logs cut from trees less than eight inches (20.3 centimetres) in diameter. Smaller sizes are called *joists*.

Before felling, it is called *standing timber*; when first cut,

it is called *rough timber;* and after it has been sawn, it is called *converted timber;* and is also known as *sided timber*, joists, plank, or board, according to dimensions.

Wood is either *soft* or *hard wood.*

The first class includes the wood of all coniferous trees, as the pines, and of a few others, as for example white birch.

The second class includes the wood of all other timber-producing trees.

The soft woods generally contain turpentine and pitch, and are usually of rapid growth, straight-grained, of slight density, quite uniform in texture, and comparatively free from knots. They have but little lateral adhesion of fibre, and are easily worked.

The hard woods are denser, heavier, and stronger, less easily sawn, split, or cut, and are more liable to warp and to crack than are the soft woods. They usually excel in durability, and in some cases are very tough and elastic.

Characteristics of Good Timber.—Good timber has the following characteristics: The heaviest is usually the strongest and most durable. That which has least sap or resin is the best.

The freshly cut surfaces are firm and smooth, and the shavings are translucent, and should nowhere appear chalky or roughened, that being the first indication of decay.

The annual rings should be closely packed, and the cellular tissue of the medullary rays should be hard and dense.

The tissues should cohere firmly, and when sawn there should be no wool-like fibre clogging the saw-teeth.

In general, the darker the color, the stronger and more durable the wood.

Inspection of Timber.—Timber should be inspected in dry weather, when the defects are not concealed by moisture.

The color should be bright and uniform, slowly changing from sap-wood to heart-wood, and free from the white spots which indicate incipient decay. Dry-rot is indicated by yellow stains.

Usually sap-wood should be thrown out, except in a few cases, as in ash, lancewood, and hickory, where it is sometimes

even better than heart-wood. The use of the centre heart-wood of mature trees is also usually avoided as being liable to early decay.

Brash-wood, which is old and brittle in consequence of age, is rejected, as is also knotty timber, twisted wood, and the timber which has been felled after having died from natural causes, like belted timber.

The preparation and inspection of small pieces is best illustrated by the regulation system adopted in the national armories with reference to securing good material for musket and rifle stocks and butts.

The wood used is the best American or Italian walnut. After seasoning about three years in the rough, or, if artificially dried, after being exposed to a temperature of 60° F. (15°.5 C.), slowly raised to 90° F. (32° C.), and held at the latter temperature six to eight weeks, the pieces are handed over to the inspector.

If defective in either of the following respects, they are rejected: *

1. Under size.
2. Misshapen.
3. Galls.†
4. Shakes.
5. Rind galls.‡
6. Discolored wood.
7. Knots or bines.
8. Crooked or cross-grain.
9. Decay.
10. Worm-holes.

They are also examined to determine whether they have been soaked in salt water, the presence of which produces rapid corrosion of the metal of barrel, lock, and mountings. The test is made by dipping a shaving into a solution of nitrate of silver; the presence of salt is shown by the formation of a white precipitate of silver chloride.

Influence of Climate and Soil.—These greatly affect the value of timber. Generally the strongest varieties of wood come from tropical climates, but the best examples of any one variety are usually from the colder portion of the range of country in which it abounds.

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* Ordnance Notes, No. 197.

† Produced by insects depositing their eggs in the tree.

‡ Due to surface injuries to the sapling.

Timber of slow growth, in situations protected from violent winds, cut at the right time of year, and properly seasoned, is free from "cracks" and "shakes," or "checks."

Cup-shakes are produced by the wrenching of the tree by winds, and are cracks separating one layer from another. Timber thus injured is sometimes called "*rolled* timber."

Longitudinal cracks are produced by heavy winds also, and by too rapid seasoning; in the latter case they are called *seasoning cracks*, in the former, *wind-shakes* or *cracks*.

Frost, in cold climates, sometimes produces this kind of injury.

Cup-shakes often injure oak, hard pine, mahogany, and elm, but they do not as generally affect soft pine.

"*Heart-shakes*," which are cracks crossing the heart-wood, sometimes single and sometimes grouped, making a "*star-shake*," affect all kinds of timber.

Decay of Timber.—Timber decays in two quite different ways, the causes of decay being, however, the same in both cases, namely, fermentation and putrefaction.

Dryness is the best preventive of decay of timber used in general construction, and wood kept dry has been found to last several centuries. Still, it finally becomes brittle and weakened, and may ultimately give way under a light load.

Water seems to act as a preservative, and some kinds of timber constantly immersed in water *not in motion* may endure for an indefinite period. The first effect of water is to dissolve out soluble matter, leaving the woody fibre or *lignine* uninjured, except perhaps very slightly by oxygen in solution in the water. This oxygen being exhausted however, no further action occurs unless a fresh supply of air-laden water displaces that originally in contact with the wood.

Alternation of moisture and dryness induces rapid decay. This takes place partly by solution and removal of a portion of the substance at each moistening, and partly by the action of oxygen dissolved in the water, a fresh supply of dissolved oxygen being furnished at each repetition of the moistening.

Continued dampness in a warm atmosphere is most favorable to fermentation, and consequently to rapid decay. This

putrefaction of woody fibre is known as "rot" among those who use timber.

The products of this decomposition are, as in cases of rapid combustion of wood, carbonic acid and water. The presence of water is necessary, as well as that of air, to the rapid progress of this chemical change, although the oxygen, which is essential, may sometimes be obtained from some source other than the atmosphere.

Sap-wood is more perishable than heart-wood, in consequence of the presence of saccharine and other matters having a peculiar tendency to fermentation. It is in consequence of this fact that the complete removal of the sap by seasoning is necessary.

Lime, by its tendency to abstract carbon, which, uniting with oxygen, combines with lime to form the carbonate, hastens the rotting of wood wherever it is damp. Dry lime and the carbonate do not have this effect.

"Wet-Rot" and "Dry-Rot" are the two forms in which the decay of timber exhibits itself.

Wet-rot occurs in any portion of the wood, if damp, and attacks the heart-wood of standing timber.

Dry-rot is usually produced by the want of circulation of air, and by high temperature, where the timber has not been well seasoned.

The most rapidly growing trees are most subject to decay, and those growing in sheltered localities are more liable to rot than those in exposed situations.

Of soft timbers, that containing most turpentine is least liable to rot.

Woodwork embedded in damp plaster, and unseasoned timber covered with a coating of paint, are subject to dry-rot, and are apt to decay early, in consequence of the confinement of air and moisture within their pores. Any thing which absorbs moisture and confines it in contact with wood is likely to accelerate decay.

Marine Animals frequently attack timber immersed in salt water, as the bottom of vessels, piles, etc.

The *Teredo navalis*, commonly known as the ship-worm,

converts the wood which it enters into a perfect honeycomb. It enters the wood when very small, and there increases in size, and enlarges its chambers correspondingly, until it sometimes makes borings an inch (2.54 centimetres) in diameter, and several feet long. Soft woods are very rapidly destroyed by it, and the hardest woods are not safe against its attacks.

The *Limnoria terebrans* is a smaller creature than the Teredo, shaped somewhat like a wood louse, and is rather more than an eighth of an inch (.3 centimetres) long. It is very destructive, cutting out the wood along the annual rings.

There are several other marine animals which attack timber, and it is usually necessary to protect it, when immersed in salt water, by sheathing with copper, as ships are protected, or otherwise covering it with a coating impenetrable by these animals.

Some kinds of timber are much less liable to this kind of injury than others. The East Indian teak is said never to be attacked by either of these creatures, and live oak is comparatively little injured by them.

The Varieties of Timber used in carpentry, joinery, and pattern-making are very numerous; and the forests of our own country yield immense quantities of some of the most useful kinds.

They are divided into two great classes:

Pine Woods, or the Coniferæ, are distinguished by their spine or needle-like leaves and resinous turpentine-yielding sap.

Leaf-wood comprehends all other timber-trees, and bears leaves of the ordinary broad, thin, and irregular shapes; its sap is destitute of turpentine.

The latter woods are usually best where strength, durability, and hardness are demanded; the former excel in lightness, elasticity, and flexibility.

The Leaf-woods are divided into two classes: (1) Those which have their medullary rays broad and well marked: (2) woods in which those rays are indistinct.

These classes include each two sub-classes: (*a*) Those in which the annual rings are distinctly marked, as in the oak of

the first, and in the ash of the second class; (*b*) those in which the rings are obscure, as in beech of the first, and walnut and mahogany of the second class.

White Pine (*Pinus strobus*) is a native of North America, and takes its name from the color of its wood. It grows in all kinds of soil. The best timber is found in cool, damp situations in the forests of the Northern United States and Canada, between the forty-third and forty-seventh parallels of north latitude. It rarely flourishes well as far south as Virginia. It grows to a great size, reaching a height of upwards of 200 feet (61 metres), with a diameter of 10 feet (3.05 metres) at the height of a man's shoulder from the ground. It is the tallest tree in our forests. It sometimes reaches the age of 350 years. Single logs have been cut 36 inches (91 centimetres) square and 60 feet (18.3 metres) long. Its wood is yellowish-white in color, light in weight, rather soft, free from knots, straight grained, and is very easily cut. It is durable only in dry air. It contains very little resin. Its leaves are very slender, and are pale green in color; its cones are nearly cylindrical, and four or five inches (10 to 12.7 centimetres) long.

Its specific gravity is about 0.70 green, and 0.50 seasoned, its weight being quoted at 44 and 30 pounds per cubic foot respectively (705 and 480 kilogrammes per cubic metre).

It is used for light carpenters' and joiners' work, and is remarkably well adapted to pattern-makers' use. It has been employed to a considerable extent in building wooden bridges.

It is not a very strong wood, and swells or shrinks seriously when the hygrometric state of the atmosphere changes considerably. For many purposes its softness is a serious objection.

The Canadian Red Pine (*Pinus resinosa*) is found growing on the poorer soils of the northern portion of the United States, and in Canada, reaching a height of 80 feet (24.4 metres), and attaining a diameter of 2 feet (.6 metres). It is wrongly called, in various localities, "Norway Pine" and "Yellow Pine."

The leaves are in pairs, and five or six inches long (12 to 15 centimetres).

The wood is fine-grained and white, with a reddish tinge, somewhat soft, but quite strong and durable. It is so soft and flexible, and so readily worked, as to be a favorite timber for light work. It makes excellent planking and spars for ships.

FIG. 131.—PINE.

The American Yellow Pine, "*Spruce Pine*," or *Short-leaved Pine* (*Pinus mitis, Pinus variabilis*), is found throughout the country, in dry sandy soils, from New England to Georgia.

It attains a height of 60 feet (18.3 metres), and a diameter of 18 inches (45.6 centimetres). The trunk is straight and slender. Its cones are small, its leaves are in groups of threes, and from 3 to 5 inches (7½ to 12½ centimetres) long.

The heart-wood is fine-grained, moderately resinous, strong and durable. The sap-wood is poor in quality, and decays rapidly.

It is much used in carpentry, and for framing and flooring, and in ship-building; it is also used for the masts and yards of large vessels.

The Southern Pine, "*Long-leaved Pine*" (*Pinus australis, Pinus palustris*), is distributed along the Atlantic coast from Maryland southward, on sandy, light soil. It is probably the most generally useful of our woods, and immense quantities are brought into market.

Its name is very commonly confused with that of the *pitch pine*, and both kinds of wood are known in the Eastern States as *hard pine*.

Both the yellow pine and the pitch pine are extensively used, by Atlantic ship-builders, for planking, beams, keelsons, etc., but seldom for any part of the frames.

The yellow pine sometimes attains a height of 150 feet

(45.7 metres), and a diameter of 4 feet (12.1 metres); but the pitch pine seldom exceeds two-thirds this size. The former is principally obtained from the States of Virginia, North Carolina, and Georgia, while the latter is abundant in all the Atlantic States south of Chesapeake Bay. The yellow pine required for navy-yard use is described as long-leaved, fine-grained, Southern yellow pine.

Its leaves are rigid, and 8 to 11 inches (20.3 to 27.9 centimetres) long; they are dark green in color. The cones are 6 to 8 inches (15.2 to 20.3 centimetres) long.

It has but little sap-wood, and the heart-wood is of very uniform quality, its resinous matter being very regularly distributed. Its grain is fine and close, and it has greater strength, durability, and hardness than any other species of pine.

Though not so tough and elastic as white oak, the yellow pine, especially that from Georgia, successfully rivals it in stiffness. If a beam of each kind of timber, equal in dimensions, be supported at the ends, the oak beam will depart most from its "mould," but will break under about the same load.

In dry situations the pine is extremely durable, and where the properties of lightness and solidity are required in combination, it is to be preferred to oak.

Experiments upon the shrinkage of various woods, by Mr. James Jarvis, at the U. S. Navy-yard, Norfolk, Va., indicate that yellow pine should be cut in summer.

The Pitch Pine (*Pinus rigida*), is common throughout our country, frequenting sandy or lean rocky soils. The best qualities come from Florida. It is distinguished by peculiarly rough, dark bark, and by the abundance of its resin. Its leaves are in groups of three, 3 to 5 inches long (7.6 to 12.7 centimetres).

The wood is close-grained, heavy, free from knots, elastic, quite strong, and very durable. It is more dense than yellow pine; which latter has the preference for all work to be covered by paint. Pitch pine is very stiff, and moderately fine-grained.

In using yellow and pitch pines, the best timber for strength and durability is not necessarily that of the greatest density. The timber of greatest weight is often heavy simply because of the presence of a surplus of turpentine in its vessels.

The Foreign Northern Pine, *Yellow Fir*, *Red Fir*, or *Scotch Fir* (*Pinus sylvestris*), is found in all parts of Northern Europe, including Great Britain, where the forests are largely composed of it.

FIG. 132.—RED FIR.

It is very much used in Europe, and is obtained in Great Britain, Norway, Sweden, and Russia, and from the Prussian ports of Memel, Dantzic, and Stettin. The logs are sometimes as large as 80 feet (24.4 metres) long and 26 inches (66 centimetres) square. The yellow deals from Christiania are most durable, but a large waste occurs in working them, in consequence of their large proportion of sap-wood.

The durability of the better quality of this timber is considered by some engineers to equal that of oak.

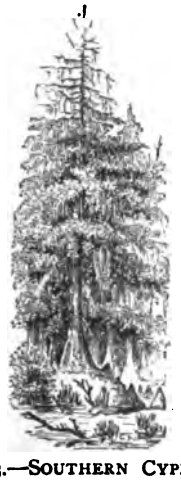

FIG. 133.—SOUTHERN CYPRESS.

Like the American white pine, it is excellently adapted for framing, and for light carpenters', joiners', and pattern-makers' work.

In Great Britain, the American white pine is, however, considerably used instead of the native fir.

The Cypress (*Cupressus disticha*, *Taxodium distichum*), or deciduous cypress, is a tree of the pine family, having a trunk sometimes 10 or even 12 feet (3.05 to 3.66 metres) in diameter, and attaining the height of from 120 to 130 feet (36.58 to 39.63 metres). Its foliage is a delicate light green in color, the leaves linear,

awl-shaped, and spreading, and borne upwards on slender branchlets.

The tree is found from the Hudson to the Gulf of Mexico, and flourishes best in southern latitudes, attaining greatest size in the swamps of the South, where the soil is a deep, rich, black, and wet mud. The roots of old trees are often partly exposed and singularly contorted. The lower portion of the trunk is frequently hollow.

The wood is considered excellent for many purposes. It is soft, light, straight-grained, and easily worked, and is imperishable where covered with water. It is extensively used in those localities throughout which it is most abundantly distributed, and sometimes as a substitute for oak.

The Qualities of Pine Timber are readily determined by a practised observer. Good wood has a close grain, and its slow growth should be evidenced by the thinness of the annual rings, which should not exceed a tenth of an inch (0.25 centimetre).

The trunk, and consequently its rings, should be symmetrical.

The best timber is charged with resin, and this preserves it from decay, and gives it strength and elasticity; its presence is indicated by strong odor. The color of the wood should be a clear tint of yellow and red, alternating, and the texture should be very uniform, as well as the colors.

The working of the timber gives a reliable indication of its quality. It should offer considerable resistance to splitting along the grain; it should be strong and free from wooliness, and the cut of the saw and of the plane or chisel should leave smooth surfaces. The shavings and chips should be strong and elastic, and the former capable of being twisted about the fingers without breaking.

The Firs are closely related to the pines, and furnish a large quantity of excellent timber to the markets of Europe and of America.

The White Fir, *Norway Spruce*, or *White Deal* (*Abies excelsa*), grows in the mountainous portions of Northern Europe. It is tall and straight, excelling all its congeners in

these respects. It reaches the height of 100 feet (30.5 metres) and attains a diameter of 3 feet (.91 metre). Its cones are cylindrical, 5 to 7 inches long (12.7 to 17.7 centimetres). It is used in Great Britain largely, being imported principally from Christiania and other Northern European ports. It is now frequently met with in North America.

This wood adheres well to glue, and is quite durable and strong, but it is not equal to the best varieties of pine.

It takes a fine polish, and is largely used for flooring and panelling, and is well adapted for spar-making.

Burgundy pitch is obtained from this tree.

THE AMERICAN BLACK SPRUCE FIR (*Abies nigra*) is so called from the dark color of its leaves. It is found in the rougher portions of the North American forest-covered country, and grows to a height of 80 feet (24.3 metres). Its cones are but 1 or 2 inches long (2.5 or 5.2 centimetres). It is quite similar in quality to the Norway spruce fir, and excels it in toughness. It is rather less durable and is less dense; it is also more liable to warp in seasoning.

FIG. 134.—"SPRUCE."

Hemlock Spruce Fir (*Abies Canadensis*) is found in the same range of climate as the black spruce, but it prefers a more hilly country. It forms extensive forests in Lower Canada. It attains a height of 70 feet (20.73 metres), and occasionally even 100 (30.5 metres), and reaches a diameter of 2 feet (0.61

metre). The leaves are dark and stiff, four-sided, and needle-shaped. The cones are ¾ or 1 inch (1.9 or 2.5 centimetres) long. The wood resembles that of the white spruce, and is generally more highly valued. Its strength, durability, lightness, and elasticity form a combination of good qualities that makes it, for some purposes, the best wood in our markets.

The Red Spruce Fir (*Abies rubra*), or *Newfoundland Red Pine*, as it is also called, grows in the north-east portions of North America, and affords an excellent material, perhaps hardly excelled by the black spruce. Its size is about the same as that of the black variety. It is especially prized for yards and spars of ships. Fir timber has a specific gravity of from 0.6 to 0.8, weighing from 36 pounds dry to 48 pounds green per cubic foot (577 to 769 kilogrammes per cubic metre).

The Larches (*Larix Europæa, Larix Americana*) are natives respectively of Europe and America. Their wood is hard and strong. Their leaves are very slender, light green in color, and short. Their cones are about one inch long. This wood has not the lightness nor the elasticity of white pine, but is tougher and more close-grained, and is far less inflammable than are woods generally.

FIG. 135.—LARCH.

Larch is hardly excelled by any other wood in durability. The European larch was celebrated for this quality from a very early period. Even when exposed to alternately wet and dry weather, it is quite durable, lasting sometimes thirty years

under most unfavorable conditions. The American variety of larch, known as Hackmatack, is highly prized by our shipbuilders. It attains a height of 100 feet (30.5 metres), and a diameter of 3 feet (.91 metre). It is found from Virginia to Canada.

The Linden, *Basswood, Lime* (*Tilia Americana, T. Europæa*, etc.), is found throughout a wide range of climate in both the United States and Europe, and has many varieties. The useful varieties are trees of moderate size, bearing large, smooth, heart-shaped leaves alternating on the stem, and having fragrant flowers which are favorites with the bees. The foliage is dense, and the tree is an excellent shade tree, but very subject to the attacks of insects.

FIG. 136.—BASSWOOD.

The wood is yellowish-white, soft, and light, but moderately close-grained and tough. It is used largely for furniture, coarse carvers' work, and to some extent in carpentry. The inner bark, or "bast," is used for making coarse matting, baskets, etc.

The Cedars and Junipers are woods of less general application than the pines; but have, nevertheless, great value in construction.

THE WHITE CEDAR (*Cupressus thyoides*) is found on the Atlantic coast of the United States from New York to Georgia, wherever the soil is wet. It is the principal inhabitant of the interior swamps of New Jersey and of Virginia, and trunks are often found of large size, sound and merchantable, lying far below the surface, embedded in mud and peat.

It grows to a height of 80 feet (24.4 metres), and to 3 feet (.91 metre) in diameter, with a straight stem and branches up to within 30 feet (9.1 metres) of the top.

Its resin is yellow, slightly odorous, and small in quantity. The cones are small, greenish in color, becoming bluish at the end of the season.

The wood is odorous, soft, fine-grained, light, and easy-working, taking a red tint, and often a decided color, when seasoned.

It resists the weather remarkably well, and is, therefore, used very extensively for shingles.

The wood makes the best of railroad ties for light traffic, but is too soft for general use; it makes excellent fencing and telegraph poles, and domestic utensils are often made of this wood. It is cut at all seasons, but best when the sap flows most slowly.

THE VIRGINIA "RED CEDAR" (*Juniperus Virginiana*) is found in nearly all parts of the United States and Canada. It is, when fully grown, from 30 to 50 feet (9.1 to 15.2 metres) high, and sometimes 12 inches (.3 metre) in diameter. It is found on dry, sterile, rough country.

The wood is light in weight, weighing 32 pounds green, and 28 pounds seasoned, per cubic foot (512 and 448 kilogrammes per cubic metre). The color of the heart-wood is red, while that of the sap-wood is white. It is brittle, compact, and durable, and has a strong characteristic odor and a bitter taste, which preserves it from the attack of insects.

FIG. 137.—CEDAR.

It is especially valuable for drawers, chests, boxes, and some kinds of furniture. When well-seasoned it makes excellent rulers and T-squares. It is extensively used for covering lead-pencils, and is sometimes called *Pencil Cedar*.

THE BERMUDA JUNIPER (*Juniperus Bermudiana*), or *Bermuda Cedar*, is a native of the West Indies. It is harder and heavier than the pencil cedar, and has a similar odor and appearance. It is very durable when well seasoned and free from sap-wood, and has been considerably used by ship-builders for planking.

These cedars, or more properly junipers, are largely used for drawers, wardrobes, and church furniture. The California "Cedars" grow to enormous size.

Tar, Pitch, and Turpentine are obtained from the more resinous trees of the pine family.

Tar is obtained by a rude distillation of the heart-wood of pine. It is viscous and semifluid at ordinary temperature, solid when cold, and quite liquid when heated. It is brownish-red in color, becoming black with age or by the presence of impurities, or by overheating when made.

It is used for preserving cordage, and the oakum which is

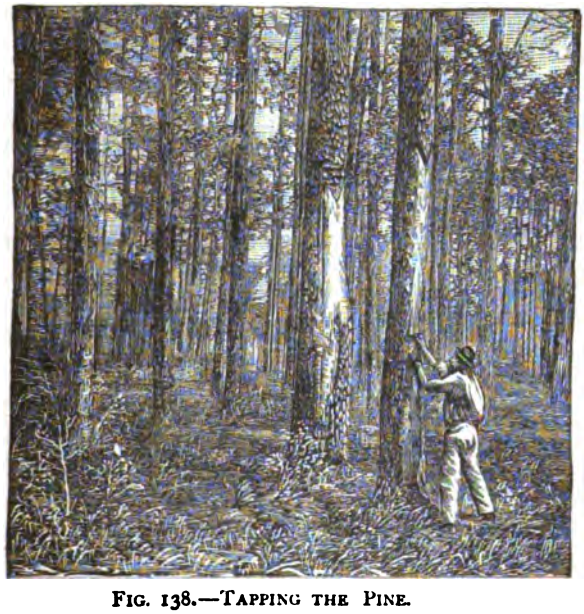

FIG. 138.—TAPPING THE PINE.

used in calking the seams of vessels, and as a binding material in artificial fuels, and in some kinds of cement.

Pitch is made by boiling tar until its consistency is considerably increased. It is hard at ordinary or low temperatures, but is softened by the heat of the hand. It is used as a cementing and preservative material. *Rosin*, or *colophony*, is a pitch obtained by distilling turpentine. The best is lightest in color.

Turpentine is the sap of the pine. The tree is tapped annually when the sap is flowing most freely. White, or "virgin" turpentine, is obtained from the tree the first season; during succeeding seasons the product becomes gradually darker, and is known as "yellow-dip." Trees are tapped twelve or fifteen years in succession. A large part of the turpentine in the market comes from North Carolina.

The following description of the process of distillation may explain further: *

A fifteen-barrel copper still, the barrel weighing 220 lbs. (100 kilogrammes), is charged early in the morning. Heat is applied until the mass attains a uniform temperature of from 212° to 316° Fahr. (100° to 158° Cent.). This is continued until the water contained in the crude turpentine as it comes from the forest has been driven off.

The first product distilled over contains pyroligneous acid, formic acid, ether, and methylic alcohol, with water. This is known as *low-wine*.

All the water having been distilled off, a small stream of cold water is now let in, so that the heat is kept at or below 316° Fahr. (158° Cent.), the boiling point of oil of turpentine. The oil of turpentine and water now come over, and the mixture is caught in a wooden tub. This tub is constructed as follows:

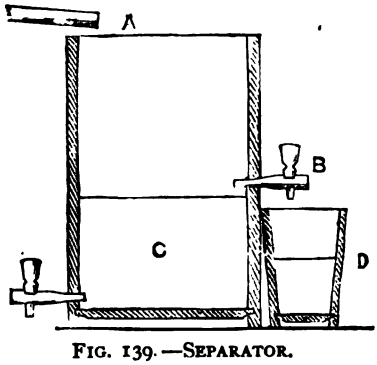

FIG. 139.—SEPARATOR.

The distillate is caught at *A* from the still, and separates into water and oil. At *B*

* *Scientific American.*

there is an overflow spout, which discharges into the tub *D*. The water is kept low enough in the lower part of the tub to prevent its overflowing through the cock *B* into the receptacle *D*. From this receptacle it is put into oak casks, well secured with iron hoops, and thoroughly glued inside.

The distiller tests the quality of the flow from time to time in a proof glass. The distillation is continued until the proportion of fluid coming over is nine of water to one of oil of turpentine. At this stage the heat is withdrawn, the still-cap is taken off, and the hot rosin, which remains in a fluid state in the still, is drawn off by a valve or cock at the side of the still near the bottom.

The yield of oil of turpentine from "virgin dip" is about 6 gallons (27 litres) to the barrel.

The yield of oil of turpentine from "yellow dip" is about 4 gallons (18 litres) to the barrel.

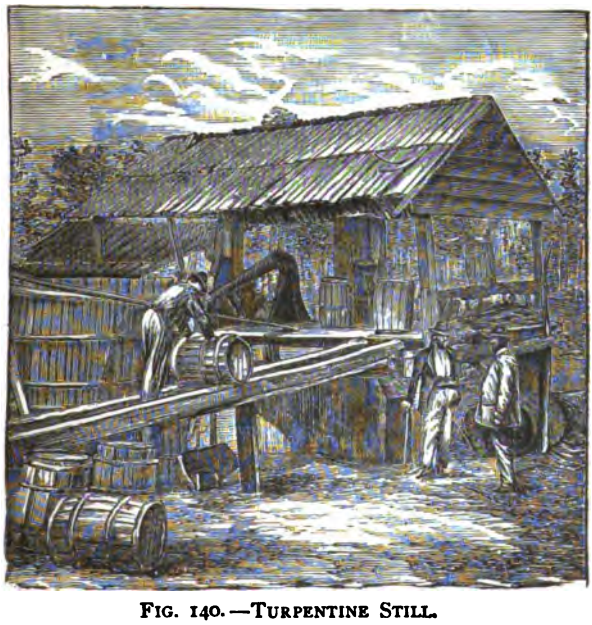

FIG. 140.—TURPENTINE STILL.

Venice turpentine is that obtained from the larch. It is sometimes imitated by mixing rosin and spirits of turpentine.

Spirits of turpentine is the essential oil of turpentine, and is obtained by distillation.

The Oaks form a most valuable class of timber-trees, and a large number of species are known and used. Of more than sixty species known to botanists, over forty are natives of North America, and several produce very excellent timber.

The best kinds of oaks are, if properly prepared for use, the hardest and most durable of woods. Kept either under water or perfectly dry, oak has been known to last several centuries. It is strong, tough, and moderately stiff. There are, however, varieties of oak which yield inferior timber, and trees of the same species may yield either superior or inferior timber, according to the nature of the soil and the climate in

FIG. 141.—OAKS.

which they have grown. The texture is alternately dense and porous.

The wood has a peculiar odor and taste, the latter being due to the presence of gallic acid, which, by contact with

iron, produces an ink which blackens the wood and corrodes the metal.

The oaks grow on a great variety of soil, preferring a clayey subsoil overlaid with rich loam.

The Live Oak (*Quercus virens*) is one of the best known ship-timber trees. It is evergreen, and grows on the sea-coast from Maryland to the Gulf of Mexico and the Mississippi, and is now so scarce and so valuable that the government has reserved all of the Florida live-oak forests for naval purposes.

The tree grows to a height of 60 feet (18.3 metres), and to a diameter of 4 feet (1.22 metres), but is usually 40 or 45 feet (12 to 13.7 metres) high, and 12 to 18 inches (30.5 to 46 centimetres) in diameter. The sap-wood is whitish in color. It is free from the glutinous matter which fills the capillary vessels of the denser heart-wood. Unlike other varieties of oak in our country, it is free from acid.

This timber is used almost exclusively for the purposes of ship-building, and is the most costly ship timber in the market. It is heavy, compact, fine-grained, yellowish in color, and is the strongest and most durable of all American woods.*

It is not well adapted to the reception of spike fastenings, as the grain refuses to receive the point in the cutting direction, and permits splitting of the wood. There is no difficulty, however, in fastening with bolts and treenails.

Live oak, if exposed long in the open air, in the rays of the sun, or to winter winds, will check badly. It does not require many months of air seasoning, however, to fit it for its ordinary uses.

The White Oak (*Quercus alba*) is a more common and a very valuable variety of oak. It is especially valuable for ship-building, for which its trunk furnishes the heavier beams, and its large roots and branches yield the compass timber.

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* The Author possesses a live-oak cane, taken in 1865 from the *keel* of the frigate *United States*, a naval vessel built very early in the present century. It is as perfectly sound, apparently, as when first cut.

It is used for water-wheel shafts and steps, and other millwrights' works, and for artillery carriages. The wood from the roots makes beautiful furniture. The cost and the difficulties of working it preclude its extensive use. The bark is rich in tannin, and is of great value for tanning leather.

FIG. 142.—WHITE OAK.

This tree is found from Canada to the Carolinas, and is most abundant in the Middle States, forming large forests west of the Alleghany range of mountains. It reaches a height of 80 feet (24.3 metres) and more, and its trunk is sometimes 6 or 7 feet (1.8 or 2.1 metres) in diameter. It is one of the few trees which retain any of their leaves throughout the winter. The leaf is deeply indented, long and narrow. Its bark is of a light grayish-white color, giving it its name; the wood is light straw-colored, with a tinge of red, and is very tough, strong, durable, elastic, and pliable, with strong lateral cohesion. It is very liable to shrink, warp, and crack in seasoning, and is therefore of little value for boards. The shrinkage amounts to about one thirty-second.

The wood of trees 60 to 100 years of age is much tougher, particularly on high lands, than that of older trees. No certain data exist for comparing the properties of white oak grown in various districts, but it is generally supposed that the best timber for durability is that grown near the Atlantic seaboard, or along the borders of the great lakes. Generally the strongest timber is grown on wet lands. The experiments of Jarvis prove, first, that there is ten per cent. in one year, and five per cent. in four years, more shrinkage in

weight of the squared timber which is cut in the warm season, than in that cut during the cold season; secondly, that in the case of round logs, in bark, there is eight per cent. in one year, and seventeen per cent. in four years, more loss by evaporation if cut in the summer season.

It has a specific gravity of from .7 to 1.1, weighing from 44 pounds, dry, to 70 pounds, green, per cubic foot (705 to 1,121 kilogrammes per cubic metre).

The Post Oak (*Quercus obtusiloba*), or *Iron Oak*, is common in Maryland, and east of the Alleghanies in Virginia, where it is also called the Box White Oak. It is occasionally found as far north as New York and New England.

It produces excellent timber, but seldom exceeds a foot or 15 inches in diameter, and a height of 50 feet (15.24 metres). The wood is of a yellowish hue, close-grained, and is often superior to the white oak in durability and strength. It is also finer grained. It is a most excellent wood for constructive purposes where of sufficient size, and is used for knees in ship-building, and for staves.

FIG. 143.—SWAMP OAK.

The Swamp Post Oak is found in the Carolinas and in Georgia, in swampy and often inaccessible districts. It is

larger than the preceding species, and is an excellent timber-tree.

The Red Oak (*Quercus rubra*) is a Canadian tree, which grows with considerably greater rapidity than either of the preceding. It is usually smaller, but attains a height of 100 feet (30.5 metres). Its leaves change to a red color before falling, in autumn, and this fact gives the tree its name.

The wood is easy to work, light and spongy, and lacks the durability of the better kinds. It is coarse-grained, and is only used to any considerable extent for staves.

The Rock Chestnut Oak (*Quercus primus monticola*) grows in the Middle States, and as far north as New England. It is most plentiful among the Alleghanies, and is more durable, and is, in other respects, nearly as valuable as the white oak, but its scarcity prevents its equally extensive use.

The Chestnut White Oak (*Quercus primus*) is found in the Southern Atlantic States.

It produces a strong and durable wood, although not equal to the white or the post oak. It is used to some extent in wheelwrights' work, and is considered nearly equal to white oak for ships' frames.

The British Oak (*Quercus pedunculata*) is found all over Europe, and is most common in England and France. It grows to a height of from 70 to 100 feet (20.7 to 30.5 metres), and attains a diameter of 6 feet (1.8 metres).

The wood has a light brown or reddish tinge, with numerous large medullary rays. It is tough and strong, quite hard, straight-grained, free from knots, splitting freely, and is said to be one of the best kinds of oak for joists, or where a stiff timber is desired.

It bears changes from wet to dry, and the reverse, well, and is almost unalterable when protected from the action of oxidizing agents, when in air or under water.

The Sessile Fruited Oak (*Quercus scssiliflora*) is another very valuable European timber-tree, which is most common in the German forests.

The wood is rather dark, of uniform color and grain,

heavy, hard, and quite elastic, resembling chestnut slightly in appearance. Like other varieties of oak, it is liable to warp and crack in seasoning. Its durability is equal to that of the preceding sort. It is somewhat more difficult to work.

The Beech (*Fagus sylvatica*) is a native of Great Britain and of Northern Europe.

Its closeness and uniformity of texture make it valuable for tool-makers and furniture manufacturers, a large proportion of ordinary English furniture being made of it. It is used in dry situations by millwrights for the cogs of mortice gears. The lighter-colored wood is best.

The American Beeches (*Fagus sylvestra* and *Fagus ferruginea*), the *white* and the *red*, are of somewhat less value, although similar in general characteristics.

It generally congregates in great quantities wherever the soil is most favorable; hundreds of acres are sometimes covered with this alone. Such tracts are familiarly called beech-woods.

Beech is used for furniture, gearing, submerged water-wheel bearings, tool handles, plane stocks, saddle-trees, wallets, chair-making, etc.

The Chestnut (*Castanea vesca*) is a native both of Europe and America. It attains a height of 70 feet (20.7 mètres), and a diameter in our Middle States of 6 feet (1.8 metres); its average size is about 45 feet (13.7 metres) high, and 2 feet (.6 metre) diameter.

It is a very long-lived tree, and has been known to attain the age of 1000 years. When of great age, it is invariably hollow, and valueless for timber.

It is very similar in color to white oak, although exhibiting a stronger contrast between sap and heart-wood than the latter. It is distinguished from oak very readily by the lack of marked medullary rays, and by its lightness.

The wood is of great value. It is extremely durable, lasting under water even longer than oak or elm. It is hard and compact, and, when young, tough and flexible; but it acquires brittleness with age. Breaking transversely, it first bends considerably, and then fractures suddenly.

FIG. 144.—THE GREAT CHESTNUT OF MOUNT ETNA.

The Ash (*Fraxinus excelsior*) of Europe, and the *White Ash* (*Fraxinus Americana*) of America, are very valuable timber-trees. They grow to a height of 60 feet (18.3 metres), and acquire a diameter of 20 inches (50.8 centimetres) in rich, moist, loamy soils. They have no observable sap-wood.

Their woods have many useful applications. Ash is quite similar in color to oak, and in texture to chestnut. It is straight-grained, remarkably tough and elastic, excelling in these qualities all other common woods, and answers admirably for handspikes, heavy oars, ship blocks, tool handles, the wooden portion and framing of machinery, and for wheel carriages and agricultural implements. It is durable under cover, but decays rapidly if exposed to the weather.

The Common Elm (*Ulmus Americana*) is a native of New England, where it attains a height of 100 feet (30.5 metres), and a diameter of 6 feet (1.83 metres) or more. It grows along river-banks and in rich soil, and is a noble, ornamental tree.

The heart-wood is brown, and the sap-wood is nearly white. The wood is porous and cross-grained, and does not split when nails are driven into it. It is most valued for its great durability in situations where it is constantly wet. It is used for piles under wet foundations, framing and sheathing around wheel pits in mills, for pumps, water-ways, the keels of ships, planking, and for flumes and water conduits. It is used also by wheelwrights.

THE EUROPEAN ELM (*Ulmus campestris* and several other species) is said to be even harder and more durable than the American, and is applied to similar uses.

It is hard, flexible, and tough, but difficult to work. The wood is used for wheel naves and rims, and for wheelwrights' use generally.

Wych Elm is the best variety.

THE CANADA ELM, or MOUNTAIN ELM (*Ulmus racemosa*), is a less valuable tree.

Its wood is close and fine-grained, flexible and tough, but it shrinks, twists, and cracks in seasoning.

The Locust, or *Common Acacia* (*Robinia pseudacacia*), is a flowering tree found in the mountainous and hilly portions of the country from Canada to the Southern States.

It grows rapidly, and reaches a height of 70 feet (20.7 metres), with a diameter of 4 feet (1.21 metres); but it is usually considered full-grown if 40 feet (12.1 metres) high, and a foot (.305 metre) in diameter. It is a fine ornamental tree.

The wood has a peculiar greenish-yellow color, slightly resembling boxwood. The structure is alternately very compact and quite porous; its annual rings are thus very distinctly marked.

It exhibits no medullary rays, and the wood has neither taste nor odor. It is a very valuable timber, especially, for fence-posts and rails, or boarding, but is seldom found of sufficient size and quantity to be used in the latter form. It turns well in the lathe, but otherwise is difficult to cut and work. It has great torsional strength and resilience, excelling all other common woods in this quality.

The Hickory, or *White Walnut* (*Carya alba*), is a tall, handsome, American timber-tree, having great value for many purposes. It is common throughout the northern and eastern portions of the United States. It grows to the height of 50 or 60 feet (15.2 or 18.3 metres), and reaches a diameter of 3 feet (.9 metre).

The wood is alternately very dense and somewhat porous, and it is one of the heaviest of our woods. It is very strong and stiff, yet elastic and tough.

The wood, when freshly cut, has a slightly bitter taste and a mild odor; it is then almost white in color, but by exposure becomes gradually darker. Its heart-wood contains brownish-colored pores.

It makes excellent cogs for mortice gears, and is well adapted for handspikes, although rather heavy, and for axles, shafts, spokes, and other wheelwrights' work.

The Black Walnut (*Juglans nigra*) is found throughout our Middle and Western States, and as far south as the Gulf of Mexico. The tree presents a fine appearance, attains considerable size, and yields a much-prized timber.

The wood varies considerably in quality. It is of a brown color, approaching red in some specimens, and of a dark chocolate color in others. The sap-wood is frequently quite light in color. The best wood has a fine grain and a dense structure, although usually excelled in both particulars by good mahogany. It is nearly as strong as mahogany, and is tougher. It is durable, and easily worked.

FIG. 145.—BLACK WALNUT.

It is more generally used in the United States for furniture and for ornamental purposes than any other wood, and immense quantities of it are annually worked up.

FIG. 146.—CHERRY.

The Cherry and Plum (*Prunus*) are found both in Europe and America. The wood is excellent, quite hard, of a pale pinkish brown, or yellow color, and of close grain. It makes very neat furniture, and is used for handles of tools. As its price is about that of panel pine, it is very extensively used for hard patterns.

The Holly (*Ilex opaca*) is an American wood, found from Maine to Pennsylvania. The tree attains a height of 30 or 40 feet (9.1 to 12.1 metres), is distinguished by the bright red of its berries, and by its glossy leaves.

The wood is white in color, close in texture, with a beautifully fine grain. It requires to be carefully and thoroughly seasoned, and then is found most excellent for "T-squares," painted wooden wares, cabinet work, blocks for calico-printers, and for turned work.

FIG. 147.—HOLLY.

The Maple (*Acer*) is another American wood. It is remarkable for the beautiful variety of its grain. It is very largely used in joiners' work, and in cabinet-making. It has been used, with good results, as a packing in pump-buckets.

The *Sugar Maple*, or *Bird's-Eye Maple* (*Acer saccharinum*), produces a sap charged with sugar, and the tree is therefore called the Sugar Maple. This wood is full of small knots which give it its name, and which make it the most beautiful of our light-colored woods.

FIG. 148.—MAPLE.

The Dogwood (*Cornus Florida*) is a small deciduous tree attaining a height of 30 feet (9.1 metres), and bearing beautiful large white flowers. It grows from Massachusetts to Florida, in moist, rich soil.

The wood is hard, fine, and close-grained, rather difficult to work, and can be given a fine polish; it is used in making tool handles, mallets, drifts, toys, harrow-teeth, hames for harnesses, and for small articles of turned work.

Mahogany (*Swietenia mahogani*) is a West Indian and Central American tree, growing in greatest size and perfection in the fertile regions of Honduras, and in the valleys of Cuba.

The tree is remarkable for its beauty of form and rapidity of growth, as well as for its noble size. Specimens measuring 20 feet (6.1 metres) in circumference are often found.

Mahogany is of various shades of brownish red, quite uniform in its tints in the same piece, but varying greatly in different specimens. The texture is very uniform, and its medullary rays and annual rings are not usually very well marked. The pores are quite noticeable, and, in mahogany from the West Indian islands, are filled with a white substance which distinguishes this variety, called also *Spanish Mahogany*, from the Honduras wood. It has no perceptible taste, and but slight odor. In seasoning, it is less subject to cracking or distortion than almost any known wood, which fact, and its exceptional beauty, make it a much sought and highly prized wood for fine furniture, and for many special uses, among which those of the pattern-maker are not the least important.

FIG. 149.—MAHOGANY.

The Honduras wood, often called *Baywood*, holds glue remarkably well.

The Spanish mahogany is imported in logs measuring, often, 2 feet (.61 metre) square, and 10 feet (3.05 metres) long. The Honduras mahogany comes in logs 14 or 15 feet (4.6 metres) long, and from 2 to 4 feet (.6 to 1.2 metres) square. The former is harder, of closer grain, and darker in color than the latter, which is comparatively porous, of irregular color, and is rather a weaker wood.

Mahogany is also found in the East Indies and in Africa. It is of excellent quality, but less beautiful than the American woods. Its specific gravity is .8.

Lignum-Vitæ (*Guaiacum officinale*) is obtained from the West Indies in logs of small size, and 3 to 12 feet (.9 to 3.6 metres) long. It is the hardest and heaviest wood generally used in the arts, its specific gravity being about 1.5. The wood is dark brown in the heart, and light yellow in the sap-wood. Its immense strength and hardness make it very valuable for sheaves of pulleys, and ships' blocks, or wherever great weight and friction are to be sustained. In making sheaves, care is usually taken to turn them so as to leave a ring of sap-wood on the outside, and the heart-wood within. The sheave is thus rendered less liable to crack.

Lignum-Vitæ is used for steps of water-wheels, for the stern or outboard bearings of the screw shafts of steam-vessels, and, occasionally, for other kinds of machinery bearings. Thus used, it bears an immense pressure under water, without wear or heating, and is better in such positions than any metal. It is necessary to secure efficient lubrication with water, as, although the friction is greater than if lubricated with oil, the latter lubricant does not effectively carry away the heat developed. The "end grain" should take the wear, if possible.

The Spanish Cedar (*Cedrela odorata*) is a West Indian wood, red in color, soft, light in weight, brittle, and odorous.

It is best known as the material of which cigar-boxes are made.

The Teak (*Tectonia grandis*) is an extremely valuable East Indian wood. It is also called Indian oak. Although comparatively little known in this country, it is very extensively used in Great Britain by ship-builders. The finest qualities come from the forests of Burmah, Ceylon, Malabar, and Java, where it grows to the height of 150 feet (45.7 metres), with wide-spreading branches, and a straight, graceful trunk which is sometimes 9 feet (2.75 metres) in diameter.

The wood is said by British ship-builders to be the best in

the world for their purposes as well as for general ship-carpentry. It has some resemblance to oak in its color, but it is rather lighter, and is more uniform in density and in compactness of grain. Its specific gravity, seasoned, is about .6. It is light, strong, and durable, and is easily worked. It seasons quickly, requiring comparatively little drying. It is somewhat liable to check.

It is less frequently attacked by insects than other woods, its peculiar oily, odorous, and perhaps poisonous, sap generally preserving it from even the white ant and from the teredo. The acidity of the sap of the common oak forbids the use of iron fastenings; but the teak, to the other good qualities of oak, adds that of preserving iron embedded in it, by its oily sap.

Camphor Wood (*Guttifera*) is also a valuable East Indian wood. It grows to a large size.

The wood is very strong, durable, and easily worked.

It weighs about 70 pounds per cubic foot (1,121 kilogrammes per cubic metre). It has a powerful odor which preserves it from the attacks of insects and of marine animals.

Boxwood (*Buxus Balearicus*) is usually of South European and Asiatic growth, but it is found also in America.

The tree is low, and the imported logs are seldom over a foot (.305 metre) in diameter.

The wood is yellow, brighter in color than our locust, with thin bark and numerous small knots, and is often twisted and somewhat unsound. It is extraordinarily smooth and compact in texture. It is used principally for small work. The engraver uses it almost exclusively, and it is largely used for rulers and scales, and for small turned work.

Ebony (*Diospyros*) is found in nearly all tropical countries. The best (*D. ebenus*) comes from Mauritius. It is black (sometimes jet black), extremely hard and heavy, with a fine, close grain. It is chiefly applied to ornamental purposes, and is used by the engineer for some kinds of model work.

A green ebony, so called (*Americanus ebenus*), is found in the West Indies.

Lancewood (*Uvaria lanceolata*) is brought from the West Indies. It is lighter in color than boxwood, splits easily, but is very tough, strong, and elastic. It is, therefore, well adapted for pole-springs, and is useful wherever an elastic and strong wood may be needed.

Greenheart (*Nectandra Rodiæi*) is brought from the West Indies and the north-east coast of South America in logs from 30 to 50 feet (9.1 to 15.2 metres) long, and from 1 to 2 feet (.61 metre) square in section.

The wood is dark green varying to dark chestnut in color, sound, straight-grained, strong, elastic, and tough. It is very heavy, having a specific gravity of about 1.15. When broken, it yields suddenly and completely. It is also very durable, resisting both weather-wear and the attacks of insects remarkably well.

It is used for ship-work, engine-keelsons, beams, and piles.

Rosewood (*Amyris balsamifera*) is a native of tropical America, the best wood coming from Brazil.

It is the most beautiful and highly prized of the dark ornamental woods. Its color is a very dark brown, or nearly black, shading off in spots into a deep, rich, brownish red, and presenting a beautiful variety of color and of patterns in its grain. It is hard and heavy, rather difficult to work, and takes a beautiful polish. It is largely used in the form of veneers.

Timber is measured, when bought in market, either by the cubic foot or by *board measure*. The unit of the latter is the square foot of one inch thickness, and is denoted by the abbreviation B.M.

Sawed or hewed timber is often measured by the cubic foot. Round timber is measured by multiplying the length by the square of one-fourth its mean girth to obtain the cubic contents.

Oak timber should measure in the shortest logs one foot or more in length for each inch in diameter. Timber supplied for general purposes is usually cut to a standard length for convenience of measurement.

CHAPTER XX.

STRENGTH OF TIMBER;

Its Special Adaptations and its Preservation.

The woods vary immensely in strength, and even in the same kind there may be a great variation among several specimens, arising from differences of age, and of climate, soil, exposure, seasoning, any circumstances, in fact, which may differently affect each individual tree. Wherever a definite statement of strength is hereafter given, it will be understood that it applies to well-preserved and well-seasoned mature specimens of the kind referred to.

As a general rule, the heart-wood of the tree is strongest and most uniform in character. If the tree has begun to decay while standing, however, the heart-wood is first affected.

A tree, sound when felled, decays externally first, the sap-wood usually rotting away much sooner than the heart.

The pines are rich in resin, which is an excellent preservative, and as it abounds principally in the heart-wood, knotty portions of these trees are almost indestructible by exposure to the atmosphere. It is evident that experience and excellent judgment are required to determine when the tree has arrived at just the proper age to yield the best and strongest timber. After the tree has been felled, the strength of its wood is largely influenced by the method of seasoning. If this be done gradually and thoroughly, the seasoned wood is far stronger than the green; sometimes it is of double strength.

If seasoned in oil, as described on page 601, on seasoning, the strength of hickory has been found by Mr. Geo. H. Corliss, who first made the most successful experiments, to be upwards of fifteen per cent. greater than good specimens seasoned in the usual manner. This is confirmed by Hirn, who found a gain due to this process of from ten to twenty per cent. with various woods.

In fir, the thinner the annual layers, the greater the coefficient of elasticity. In other woods, no difference was detected, arising from this cause.

Timber has no defined limit of elasticity. One is taken by some writers, assuming as a limit in extension that point at which the set becomes $\frac{1}{20,000}$ of the original length (.00,005 *l*). It may be taken, for purposes of estimation, at one-third or one-fourth of the breaking weight.

Coefficients of Elasticity.—The following values of *E* are given by various experimenters:

COEFFICIENTS OF ELASTICITY.

	BRITISH.	METRIC.
	Lbs. on Sq. In.	Kg. on Sq. Centim.
Ash	1,600,000	112,480
Box	1,800,000	126,540
Chestnut, dry	1,250,000	91,250
Elm	1,500,000	105,450
Fir, Baltic	1,800,000	126,540
Fir, New England	1,200,000	84,360
Larch	1,400,000	98,420
Lignum-Vitæ	1,000,000	70,300
Mahogany	1,400,000	98,420
Oak, English	1,700,000	119,510
Pine, Pitch	1,900,000	133,570
" Red	1,800,000	126,540
" Yellow	1,600,000	112,400
" White	1,000,000	70,380
Teak, Indian	2,100,000	147,030
Willow	1,400,000	98,420

The Factors of Safety used with the woods are generally large, especially where the attempt is made to use it in tension, or when beams are fished or scarfed. They may be taken, for ordinary work, at 5 for "dead" loads, 10 for a moving load, and 10 to 20 under shock. In the latter case, however, they should be carefully determined after calculation of the resilience of the parts attacked.

The Tenacity of timber is very variable. The following are values of *T* for good samples.

CO-EFFICIENTS OF TENSILE RESISTANCE.

	BRITISH.	METRIC.
	Lbs. per Sq. In.	Kg. per. Sq. Cm.
Ash	10,000 to 15,000	703 to 1,055
Birch, Black	7,000 " 10,000	492 " 703
Beech	8,000 " 12,000	562 " 844
Box	10,000 " 15,000	703 " 1,055
California Spruce	12,000 " 14,000	844 " 984
Cedar, Bermuda	4,000 " 7,500	281 " 527
" Guadaloupe	5,000 " 9,500	352 " 668
Chestnut	7,000 " 10,500	492 " 738
" Horse	8,000 " 12,000	562 " 844
Cypress	4,000 " 6,000	281 " 422
Elm	8,000 " 13,000	562 " 914
Fir (New England Spruce)	5,000 " 10,000	352 " 703
" Riga	5,000 " 12,500	352 " 879
Greenheart	6,000 " 9,000	422 " 633
Holly	10,000 " 15,000	703 " 1,055
Hickory, American	10,000 " 14,000	703 " 984
Lancewood	8,000 " 15,000	562 " 10,55
Larch	6,000 " 10,000	422 " 703
Lignum-Vitæ	10,000 " 12,000	703 " 844
Locust	10,000 " 15,000	703 " 1,655
Mahogany, Honduras	5,000 " 8,000	350 " 560
" best Spanish	8,000 " 15,000	562 " 1,055
Maple	8,000 " 10,000	562 " 703
Oak, American Live	10,000 "	703 ....
" " White	10,000 "	703 ....
" English	9,000 "	633 ....
" best English	12,000 "	844 ....
Oregon Pine	9,000 " 14,000	633 " 984
Pear	7,000 " 10,000	492 " 703
Pine, Pitch	8,000 " 10,000	562 " 703
" Red	5,000 " 8,000	352 " 562
" White	3,000 " 7,500	362 " ....
" Yellow	5,000 " 12,000	352 " 844
Plum	7,000 " 10,000	492 " 703
Poplar	7,000 "	492 " ....
Spruce	5,000 " 10,000	352 " 703
Teak	10,000 " 15,000	703 " 1,055
Walnut, Black	8,000 "	562 ....
Willow	10,000 "	703 ....

Across the grain the tenacity is much less, being for the pines and spruce woods from one-tenth to one-twentieth; and in harder woods from one-sixth to one-fourth the figures just given. In oak it is one-fourth, in pine hardly one-tenth.

The Crushing Resistance of timber is as variable as its tenacity. Mean values for good quality only can be given.

The following *Moduli of Crushing Strength* are deduced from experiments upon pieces one inch (2.54 centimetres) in diameter, and two inches (5.08 centimetres) long.

Hodgkinson found the compressive strength of wet wood to be frequently less than half that of dry.

COEFFICIENTS OF RESISTANCE TO CRUSHING.

[In direction, parallel with fibres.]

	BRITISH.	METRIC.
	Lbs. per Sq. In.	Kg. per Sq. Cm.
Alder	6,000 to 7,000	422 to 492
Ash	4,600 " 8,000	323 " 562
Beech	8,000 " 9,000	562 " 633
Birch	6,000 " 10,000	422 " 703
" English	5,000 " 6,500	352 " 457
Box	8,000 " 10,000	562 " 703
Cedar	4,000 " 6,500	281 " 457
Cherry	5,000 " 6,500	352 " 457
Chestnut	4,000 " 4,800	281 " 337
Elm	8,000 " 10,000	562 " 703
Greenheart	10,000 " 14,000	703 " 984
Hickory	8,000 " 9,800	562 " 689
Larch	3,000 " 5,500	211 " 387
Locust	7,500 " 9,500	527 " 668
Lignum-Vitæ	8,000 " 9,600	562 " 675
Maple	5,000 " 6,000	352 " 422
Mahogany, Spanish	7,000 " 8,000	492 " 562
Oak, English	6,500 " 10,000	457 " 703
" Live	8,000 " 10,000	562 " 703
" White	5,500 " 8,000	587 " 562
Pear	..... " 7,500	537 " ...
Pine, Red	6,000 " 7,500	422 " 527
" White	3,000 " 6,000	211 " 422
" Yellow	6,500 " 10,000	457 " 703
Spruce	4,500 " 6,000	316 " 422
Teak	6,000 " 10,000	422 " 703
Walnut, Black	5,600 " 7,000	394 " 492
" White	7,500 " 9,000	527 " 633
Willow	3,000 " 6,000	211 " 422

In many cases it will be noticed that the tensile strength of wood is double its resistance to crushing, even in short pieces.

In tests hereinafter referred to the author has found the following coefficients of compression, material tested dry: *

COEFFICIENTS OF RESISTANCE TO CRUSHING.

	BRITISH.	METRIC.
California Spruce	9,200 to 12,800	647 to 900
Oregon Pine	9,200 " 11,500	647 " 808

Across the grain, the resistance to crushing is from 1,000 lbs. per square inch (703 kilogrammes per square centimetre) upward, with various ordinary woods, but very few experiments have been made to determine it.

A pressure of 1,000 pounds per square inch (703 kilogrammes per square centimetre) indents white pine .1 inch (.25 centimetre); yellow pine, .004 (.01 centimetre); and the hard woods to an extent which is too slight to be detected.

Long Pillars yield by bending. A long series of experiments were made by Hodgkinson, and his principal deductions were the following:

Flat-ended pillars, of considerable length in proportion to their diameter, offer about three times the resistance of similar pillars with rounded ends.

One end being rounded and the other flat, the pillar has a strength which is the arithmetical mean between the previous two cases.

Both ends being fixed in one case, and both rounded in another, the cross-section being equal, a pillar of a given length in the second case has no more strength than one of double that length and of the first form.

The strength of a pillar may be increased one-seventh by enlarging it in the middle.

Hodgkinson's Formulas; Gordon's.—Hodgkinson

* Some of the best experimental work on the strength of American woods has been done by Mr. R. G. Hatfield, and the results are published in the *American House Carpenter*, John Wiley & Sons, publishers.

deduced from experiment, for the formula of Euler, for square, flat-ended, oak timber:

$$P = 10.95 \frac{d^4}{L^2}$$

and for red pine,

$$P = 7.81 \frac{d^4}{L^2}$$

in which

P = crushing weight in gross tons,
d = thickness of the pillar in inches,
L = length of pillar in feet.

Where the pillar is less than thirty, and more than four or five diameters in length,

$$W = \frac{PCK}{P + \frac{3}{4} CK}$$

where

W = strength of the column in gross tons.
P = the strength given by the preceding formulas (7 or 8).
C = the modulus of crushing resistance given in the table.
K = the area of cross-section in square inches.

A more usual formula is, in form, that of Gordon, sometimes called Rankine's. Rankine's modification of the latter is the following; the crushing weight in pounds:

$$P = \frac{fS}{1 + \frac{l^2}{ad^2}}$$

in which S is the sectional area in square inches, a and f constants, and l and d the length and diameter in inches. He gives for the value of a and f, for timber, 188 and 7,200 respectively. The experiments of C. S. Smith give, for well-seasoned yellow pine, $f = 5{,}000$, $a = 250$.

Morin adopts Euler's rule:

$$P' = A \frac{d^4}{l^2},$$

in which P' is the load in kilogrammes, d the diameter in cen-

timetres, and l the length in decimetres. A is taken for pine timber at 160 for a safe load. This value of A varies with the modulus of resistance to compression.

It is good practice invariably to limit the load on columns and other struts, to that which fails to cause perceptible flexure, and never to exceed that which causes deflection to a degree beyond which a great increase may be expected to occur with comparatively little additional load. This latter point is reached with from one-third to one-half the breaking load.

In making struts of timber, Laslett states that his experiments indicate that the ratio of area of cross-section in square inches to length of inches, should not be less than from about 0.8 to 1.0 (using metric measures, cross-section in square centimetres = 2 length in metres), and that a resistance to crushing may then be anticipated of nearly the maximum obtained with cubic specimen, which conclusion is also reached by later experimenters. The relative values of timber and iron for columns are not far from the ratio of 1 to 10.

It is sometimes necessary, in very long columns, to secure stiffness, as well as strength. The following formulas are given in *Tredgold's Carpentry*, for pillars above thirty diameters long:

$$W = A\frac{d^4}{L^2} \text{ for square pillars}$$

$$W = A\frac{b \cdot t^3}{L^2} \text{ for rectangular, and}$$

$$W = A\frac{d^4}{1.7L^2} \text{ for cylindrical pillars,}$$

where

W = safe load in pounds,
b, t, and d = the breadth, thickness, or diameter in inches,
L = the length in feet.

The value of the coefficient A is about 1,500 for beech, chestnut, elm, and white pine; 2,000 for ash and mahogany; 2,500 for teak and Dantzic oak, and 2,200 for red pine.

Columns for Mills.—During the year 1881, Prof. Lanza,* of the Massachusetts Institute of Technology, conducted a series of experiments on full-sized wooden columns, for the purpose of determining what shape and proportions were best adapted for the support of mill flooring.

Two series of tests were made, also, to determine the actual crushing strength of the wood used, with the following results:

RESISTANCE TO CRUSHING.

	LBS. PR. SQ. IN.	KG. PR. SQ. CM.
Average crushing strength of Yellow Pine.....	4,392	307.5
" " " White Oak.....	3,323	232.6
" " " Whitewood	3,009	210.6

These figures are deduced from the tests of unselected material, and therefore fall considerably below those ordinarily given.

For comparison with the above the following tables, of results obtained at the Watertown Arsenal, will be found interesting:

CRUSHING STRENGTH OF YELLOW PINE,
Very Straight Grained, Twenty Years' Seasoning.

ARSENAL NUMBER.	LENGTH. INCHES.	LENGTH. CENTIMETRES.	FORM OF SECTION.	DIMENSION OF SECTION. INCHES.	DIMENSION OF SECTION. CENTIMETRES	CRUSHING STRENGTH. LBS. PER SQ. IN.	CRUSHING STRENGTH. KILOS. PER SQ. CM.	
573	20.4	51.82	Circular.	10.2 diam.	25.91 diam.	6,676	467.32	
578	119.95	304.67	Rectangular..	10.97 × 11	27.86 × 27.93	6,230	436.1	
579	119.9	304.67	"	10.96 × 10.96	27.85 × 27.85	6,552	458.64	
582	20	50.8	"	9 × 9	22.86 × 22.86	8,322	582.54	All from one piece of timber.
583	16	40.64	"	8.02 × 8.02	20.37 × 20.37	8,165	571.55	
584	..	.....	"	4 × 4	10.16 × 10.16	7,394	517.58	
585	3	7.62	"	1.5 × 1.5	3.81 × 3.81	5,593	387.31	
586	6	15.24	"	3 × 3	7.62 × 7.62	8,644	605.08	
587	6	15.24	"	3 × 3	7.62 × 7.62	8,133	569.31	
588	3	7.62	"	1.5 × 1.5	3.81 × 3.81	8,329	583.03	
589	3	7.62	"	1.5 × 1.5	3.81 × 3.81	8,302	581.14	
590	3	7.62	"	1.5 × 1.5	3.81 × 3.81	6,355	444.85	
Average.....						7,386	517.02	

* Boston *Journal of Commerce*, January 28, 1882.

CRUSHING STRENGTH OF YELLOW PINE.

Very slow growth.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
591	14	35.56	Rectangular	4.6 × 4.6	11.68 × 11.68	9,947	696.29
592	17.2	43.69	"	" "	" "	10,250	717.5
593	19.1	48.51	"	5.3 × 5.3	13.46 × 13.46	7,820	547.4
Average						9,339	653.73

CRUSHING STRENGTH OF YELLOW PINE.

Very green and wet.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
691	180	459	Open rect.	16 × 13.65	40.64 × 34.67	3,070	212.1
692	180	459	"	16.2 × 7	41.15 × 17.78	2,795	195.65
714	180	459	"	17 × 8.75	44.18 × 22.22	3,180	222.6
Average						3,015	211.05

CRUSHING STRENGTH OF SPRUCE.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
565	24	60.96	Rectangular.	5⅜ × 5⅜	13.65 × 13.65	4,946	346.22
566	24	60.96	"	" "	" "	4,811	336.77
567	36	91.44	"	" "	" "	4,874	340.98
568	36	91.44	"	" "	" "	4,500	315.00
569	60	152.4	"	" "	" "	4,451	311.57
570	60	152.4	"	" "	" "	4,943	346.01
571	120	304.68	"	" "	" "	3,967	277.67
572	120	304.68	"	" "	" "	4,908	343.56
	60	112.4	"	" "	" "	5,275	369.25
	30	7.62	"	" "	" "	5,372	376.04
	15	38.08	"	" "	" "	5,754	402.78
977	121.2	307.85	Circular.	12.4 diam.	31.5	4,681	327.67

We have the following average values for crushing strength of yellow pine:

RESISTANCE TO CRUSHING.

	LBS. PER SQ. IN.	KLS. PR. SQ. CM.
Pine, straight grained, well seasoned, Arsenal test	7,386	517.02
" slow growth, " " " "	9,339	653.73
" very green and wet, " "	3,015	211.05
" as used in Lanza's tests	4,400	308.00
" C. Shaler Smith's tests	5,000	350.00

This shows a great variation between the figures of carefully made and authentic tests. These differences are evidently due both to the selection of timber and to the seasoning of material.

Lanza recommends that columns should be bored from one end only, and this boring should extend throughout the length of the column. When columns are bored from both ends so as to meet in the middle, the two borings are apt to be eccentric, thereby weakening the piece.

The object of the boring is to allow free access of the air to all parts of the wood.

Resistance to Shearing is offered when it is attempted to divide the piece by a pair of forces acting along the same line in opposite directions, and parallel to the plane of separation.

The shearing may take place in the case of timber, either along the grain on a plane parallel to the direction of the fibre, or across the grain in the same plane, or it may take place in a plane to which all the fibres are perpendicular. In each of these three cases, the modulus of shearing resistance has a different value.

In each case the resistance is proportional to the area of the section ruptured, and is generally independent of its form. Where, however, the form is such that all parts of the section strained cannot act together in resisting shearing, the modu-

lus may be greatly reduced. Where, for example, the section is long and narrow, it will yield far more readily when attacked at the narrow, than when the shearing begins on the wider side.

The following values of the *Modulus of Shearing*, are given by R. G. Hatfield for cases where the force acts along the grain, and parallel with the fibres:

COEFFICIENT OF DETRUSIVE SHEARING.

	BRITISH.	METRIC.		BRITISH.	METRIC.
	Lbs. per Sq. Inch.	Kg. per Sq. Cm.		Lbs. per Sq. Inch.	Kg. per Sq. Cm.
Chestnut.....	690	48	Pine, Ohio.....	388	27
Hemlock.....	540	38	" Spr'ce (Fir)	470	33
Locust.....	1,180	83	" White....	490	34
Oak.....	780	55	" Yellow...	510	36

A knowledge of this modulus is necessary in properly proportioning the joints in tie-beams, and the depth of notches at the foot of rafters.

Following are values of the modulus of detrusive shearing in cases where the force acts perpendicular to the fibres:

COEFFICIENTS OF DETRUSIVE SHEARING ACROSS THE GRAIN.

	BRITISH.	METRIC.		BRITISH.	METRIC.
Larch (Hackmatack)	1,000	70	Red Pine.....	800	56
Oak.....	4,000	280	Spruce Pine.....	600	42

Trautwine obtains by experiment the following values of the shearing resistance of American woods, where rupture is produced across the axis of the piece.

RESISTANCE TO TRANSVERSE SHEARING.

WOODS.	LBS PER SQ. INCH.	KGS. PER SQ. CM.	WOODS.	LBS. PER SQ. INCH.	KGS. PER SQ. CM.
Ash.....	6,280	440	Hickory.....	6,045 to 7,285	23 to 511
Beech.....	5,223	366	Locust.....	7,176	503
Birch.....	5,595	392	Maple.....	6,355	445
Cedar, White.	1,372 to 1,519	96 to 107	Oak, White...	4,425	310
" C. Am.	3,410	239	" Live....	8,480	595
Cherry.....	2,945	206	Pine, White ..	2,480	174
Chestnut.....	1,535	108	" Yellow.	4,340 to 5,735	304 to 402
Dogwood.....	6,510	456	Poplar.....	4,418	310
Ebony.....	7,750	543	Spruce.....	3,255	228
Gum.....	5,890	413	Walnut, Black	4,725	331
Hemlock.....	2,750	193	Walnut, White	2,830	199

Fairbairn found that the resistance offered to forcing a ball three inches (7.62 centimetres) in diameter, through three-inch (7.62 centimetres) oak plank, was about the same as with quarter-inch (.63 centimetre) boiler plate, 17,000 pounds (7,727 kilogrammes).

Rupture by Cross-breaking more frequently occurs with timber than any other kind of rupture, owing to the fact that it is more usually subjected to cross strains in situations where it is generally applied.

The relation between the stress and the character of the molecular change which it produces, has been made a subject of frequent mathematical investigation from the time of Galileo, who seems to have been the first to attack the problem analytically. Such discussions have properly no place here, as the engineer will learn the theory of the subject from special treatises on strength of materials.*

Where any beam is fixed at both ends, it is found in all actual cases that the formula gives it credit for more strength than it really has, and that it is more liable to break in the middle than at either end, although the analysis which determines the formula indicates that this liability is the same at each of the three points. Barlow has therefore recommended for the special case that the formula read

$$P = \frac{Rbd^3}{l},$$

* See Wood's *Resistance of Materials*, N. Y., J. Wiley & Sons, 1877.

as more nearly approaching the conditions of practice. The discrepancy probably arises from the fact, that in practice the beam is not perfectly "fixed" in the sense in which that word is used above.

The following values of R, the modulus of rupture, in timber, have been determined by various authorities, and are given as close approximations for timber in good condition. The units are pounds and inches, kilogrammes and centimetres.

MODULI OF RUPTURE OF WOODS.

	BRITISH.	METRIC		BRITISH.	METRIC
Ash	12,000	844	Lignum-Vitæ	12,000	844
Beech	9,000	633	Locust	12,000	844
Birch, American	9,500	668	Mahogany, Spanish	8,000	562
Box	8,500	598	" Honduras	10,000	703
Cedar, West Indian	8,000	562	Maple	8,000	562
Cherry	8,000	562	Oak, Canadian	10,000	703
Chestnut	7,000	492	" English	10,000	700
Ebony, West Indian	15,000	1,055	" European	10,000	703
Elm	8,000	562	" Live	12,000	844
Fir, New England	7,000	492	" White	11,000	773
" Riga	7,000	492	Pine, Pitch	8,000	562
" Norway	7,000	492	" Red	8,000	562
" American Spruce	7,000	492	" Yellow	10,000	703
Hemlock	7,000	492	Teak	15,000	1,055
Lancewood	15,000	1,055	Walnut	12,000	844
Larch, European	8,000	762	Willow	7,000	492
" American	10,000	703	Whitewood (Basswood)	8,000	562

From the records of about forty tests of California spruce and Oregon pine, made by the Author at the Stevens Institute of Technology for the U. S. Geological Survey during the year 1880, the following results are taken:

MODULUS OF RUPTURE (MEAN).

	BRITISH.	METRIC.
California Spruce	12,228	845
Oregon Pine	11,071	775

Beams of the same material vary greatly in strength, and they sometimes break under one-fourth the load corresponding to their coefficients as above given, even when apparently sound. A large factor of safety is hence advisable.

A solid cylinder varies in strength as the cube of its diameter. The formula for this case becomes, where fixed at one end and loaded at the other,

$$P = \frac{Rd^3}{1.7 \times 6 \times l}$$

and if uniformly loaded this value P is doubled. Supported at the ends and loaded in the middle, P becomes quadrupled; supported at both ends and uniformly loaded, it is eight times as great.

A beam *supported* at one end, *fixed* at the other, and loaded uniformly, has the same strength as the last case, as has also a beam fixed at both ends, and loaded in the middle. When fixed at both ends and uniformly loaded, the value of P is twelve times as great as in the first of the preceding cases. The latter statement of the relative strength of beams differently placed is correct for all solid beams.

A wooden beam of triangular section, supported at both ends, is about *one-sixth* stronger with its base upward than with its base downward.

The strongest beam of rectangular section that can be cut from a round log, has a breadth proportioned to its depth, as 1 is to $\sqrt{2}$, or nearly as 5 to 7. Such a beam is 10 per cent. stronger than the beam of square section that might be cut from the same log. The most resilient beam has its breadth and depth equal. Placing the beam with its annual layers in the plane in which the load acts increases its resistance in the proportion of 8 to 7 nearly.

The following, in British measures, are the dimensions and safe distributed loads of sound pine beams, for each inch of thickness, as used in ordinary work.

In metric measures the loads are approximately metric "*tonnes*," of 1,000 kilogrammes, for depths in centimetres as given, and per ¼ decimetre width.

LOADS ON YELLOW PINE BEAMS.

SAFE UNIFORMLY DISTRIBUTED LOADS IN TONS OF 2,000 LBS. FOR RECTANGULAR BEAMS ONE INCH IN THICKNESS.

Span in feet.	DEPTH IN INCHES AND CENTIMETRES.															
	1 2.5	2 5.0	3 7.5	4 10.0	5 12.5	6 15.0	7 17.5	8 20.0	9 22.5	10 25.0	11 27.5	12 30.0	13 32.5	14 35.0	15 37.5
1	0.069	0.278	0.625	1.111	1.736	2.500	3.403	4.444	5.625	6.944	8.403	10.000	11.737	11.611	15.625
2	0.035	0.139	0.312	0.556	0.868	1.250	1.701	2.222	2.812	3.472	4.201	5.000	5.868	6.806	7.812
3	0.023	0.093	0.208	0.370	0.579	0.833	1.134	1.481	1.875	2.315	2.801	3.333	3.912	4.537	5.208
4	0.017	0.069	0.156	0.278	0.434	0.625	0.851	1.111	1.406	1.738	2.101	2.500	2.934	3.403	3.906
5	0.014	0.056	0.125	0.222	0.347	0.500	0.681	0.888	1.125	1.389	1.681	2.000	2.347	2.722	3.125
6	0.012	0.046	0.104	0.185	0.289	0.417	0.567	0.741	0.938	1.157	1.400	1.667	1.956	2.269	2.604
7	0.010	0.040	0.089	0.159	0.248	0.357	0.486	0.635	0.804	0.992	1.200	1.429	1.677	1.944	2.232
8	0.009	0.035	0.078	0.139	0.217	0.312	0.425	0.555	0.703	0.868	1.050	1.250	1.467	1.701	1.953
9	0.008	0.031	0.069	0.123	0.193	0.278	0.378	0.494	0.625	0.772	0.934	1.111	1.304	1.512	1.736
10	0.007	0.028	0.062	0.111	0.174	0.250	0.340	0.444	0.562	0.694	0.840	1.000	1.174	1.361	1.562
11	0.006	0.025	0.057	0.101	0.158	0.227	0.309	0.404	0.511	0.631	0.764	0.909	1.067	1.237	1.420
12	0.006	0.023	0.052	0.093	0.145	0.208	0.284	0.370	0.469	0.579	0.700	0.833	0.978	1.134	1.302
13	0.005	0.021	0.048	0.085	0.134	0.192	0.261	0.342	0.433	0.534	0.646	0.769	0.903	1.047	1.202
14	0.005	0.020	0.045	0.079	0.124	0.179	0.243	0.317	0.402	0.496	0.600	0.714	0.838	0.972	1.116
15	0.005	0.019	0.042	0.074	0.116	0.167	0.227	0.296	0.375	0.463	0.560	0.667	0.782	0.907	1.042
16	0.004	0.017	0.039	0.069	0.109	0.156	0.213	0.278	0.352	0.434	0.525	0.625	0.734	0.851	0.977
17	0.004	0.016	0.037	0.065	0.102	0.147	0.200	0.261	0.331	0.408	0.494	0.588	0.695	0.801	0.919
18	0.004	0.015	0.035	0.062	0.096	0.139	0.189	0.247	0.312	0.386	0.467	0.556	0.652	0.756	0.868
19	0.004	0.015	0.033	0.058	0.091	0.132	0.179	0.234	0.296	0.365	0.442	0.526	0.617	0.716	0.822
20	0.003	0.014	0.031	0.056	0.087	0.125	0.170	0.222	0.281	0.347	0.420	0.500	0.587	0.681	0.781
21	...	0.013	0.030	0.053	0.083	0.119	0.162	0.212	0.268	0.331	0.400	0.476	0.559	0.648	0.744
22	...	0.013	0.028	0.051	0.079	0.114	0.155	0.202	0.256	0.316	0.382	0.455	0.533	0.619	0.710
23	....	...	0.027	0.048	0.075	0.109	0.148	0.193	0.245	0.302	0.365	0.435	0.510	0.592	0.679
24	...	...	...	0.046	0.072	0.104	0.142	0.185	0.234	0.289	0.350	0.417	0.489	0.567	0.651
25	...	...	...	...	0.069	0.100	0.136	0.178	0.225	0.278	0.336	0.400	0.469	0.544	0.625
26	...	...	...	...	...	0.096	0.131	0.171	0.216	0.267	0.323	0.385	0.451	0.524	0.601
27	...	...	...	...	...	...	0.126	0.165	0.208	0.257	0.311	0.370	0.435	0.504	0.579
28	...	...	...	...	...	...	...	0.159	0.201	0.248	0.300	0.357	0.419	0.486	0.558
29	...	...	...	...	...	...	...	...	0.196	0.239	0.290	0.345	0.405	0.469	0.539
30	...	...	...	...	...	...	...	...	...	0.231	0.280	0.333	0.391	0.454	0.521

These loads are about one-eighth the breaking load. Beams supported.

RULE.—*To find the safe uniformly distributed load* for yellow pine beams, multiply the number given in the table by the thickness of the beam in inches, or take 0.4 the given number for load per centimetre of thickness. For beams of other wood, multiply by the following numbers:

White Oak.	White Pine.	Hemlock.	White Cedar.	Spruce.
1.45	.95	.95	.65	.85

The Stiffness of Beams varies as their breadths, and as the cube of their depths.

As the strength only varies as the square of the depth, it follows that large beams will be found to bend less, before breaking, than will small beams. From this fact, also, it happens that it becomes necessary, with flexible wood of comparatively small scantling, to proportion them to bear a given load with a certain limited deflection, rather than with reference to their absolute strength. In using any material the necessity frequently arises for employing formulas, expressing stiffness rather than strength, in order to secure the requisite rigidity of parts.

The stiffest beam which can be cut from a round log has its breadth and depth proportioned as 1 is to $\sqrt{3}$, or nearly as 1 to 1.732 = ·577+ to 1.

Formula for Flexure.—The following formula represents the flexure of beams of rectangular section, lying on two supports, and loaded in the middle:

Let D = the deflection, in inches or centimetres,
L = the length between bearings, in feet or metres,
P = the weight, in pounds or kilogrammes,
b and d = the breadth and depth, in inches or centimetres:

$$D = \frac{CPL^3}{bd^3}$$

C is a constant determined by experiment for each material. On page 99 are its values as given by the best authorities. In metric measure $C_m = C \times 8000$, nearly.

It is generally assumed that timber should not be loaded to a deflection greater than $\frac{1}{360}^{\text{th}}$ its length. In such cases, $30D = L$, and, substituting this value, we get from (23), British measures:

$$C = \frac{bd^3}{30L^3P}, \quad \text{and} \quad P = \frac{bd^3}{30L^3C}$$

Where beams are fixed at one end and loaded at the other, they deflect 16 times as much as when supported at

both ends, and loaded in the middle.* Hence, for this case, the values of C above given must be increased in this proportion; the formula then becoming

$$D = \frac{16PL^3C}{bd^3}$$

COEFFICIENTS OF DEFLECTION.

	BRITISH.	METRIC		BRITISH.	METRIC
Ash	0.00030	2.5	Maple	0.00040	3.0
Beech	0.00030	2.5	Mahogany, Spanish	0.00030	2.5
Birch	0.00030	2.5	" Honduras	0.00025	2.0
Cedar	0.00030	2.5	Oak, minimum	0.00025	2.0
Cherry	0.00040	3.0	" maximum	0.00050	4.0
Chestnut	0.00025	2.0	" mean value	0.00040	3.0
" Spanish	0.00050	3.5	Pine, White	0.00025	2.0
Elm	0.00030	2.5	" Pitch	0.00030	3.5
Fir, Am. Spruce	0.00025	2.0	Teak	0.00030	2.5
" Hemlock	0.00025	2.0	Walnut	0.00025	2.0
Larch	0.00030	2.5	Willow	0.00060	5.0

If, in this latter case, the load should be uniformly distributed, the formula becomes:

$$D = \frac{0.625\,CPl^3}{bd^3} \quad . \; . \; (26); \qquad D = \frac{12Pl^3C}{bd^3}$$

The formulas just given for the deflection of beams are those most generally used. A less simple, but possibly more accurate formula has been proposed by Prof. W. A. Norton, and is well supported by the experiments from which he deduces it. Δ = the deflection of a piece supported at the ends, loaded at the middle (l, b, d are in inches):

$$\Delta = \frac{Pl^3}{4Ebd^2} + C\frac{Pl}{bd}.$$

C is given at 0.0,000,094; E = 1,427,965 pounds for pine.

* Trautwine gives 24 for beams as fixed in practice.

Beams should be made as deep as possible, provided they are not made of such depth as to be liable to overturn and break sideways. A formula to determine the proper proportions of section is the following, which is given for use in general practice:

$$b = 0.6\frac{L}{\sqrt{d}}$$

The *stiffest* rectangular beam that can be cut from any cylindrical log has its thickness equal to one-half the diameter of the log. Beams of square section are equally stiff in whatever direction they may be bent. A beam fixed at both ends has twice as great stiffness as one merely supported.

In framing, therefore, the joists should be made of as great length as possible, in order that they may extend over the greatest number of supports; and they should invariably be notched over the latter, where possible.

Working Loads for Floor-beams.—C. J. H. Woodbury, of Boston, Mass.,* gives the following formulas, deduced from experiments on beams used in mill floors. The measures, as will be seen, are all British:

Let h = depth of beam, inches.
b = breadth of beam, inches.
d = deflection, inches.
l = span, feet.
s = width of load, feet.
w = distributed load per square foot of floor, including its own weight, lbs.
u = weight of floor per square foot, lbs.
w' = distributed load upon square foot of floor, not including weight of floor, in lbs.
W = concentrated load on floor, lbs.
R = modulus of rupture, lbs. per square inch.

* See a paper read before the American Society of Mechanical Engineers (1881), and *Fire Protection of Mills*, by C. J. H. Woodbury; N. Y., J. Wiley & Sons, 1882.

E = modulus of elasticity, lbs. per square inch.
f = factor of safety, in units.

Assuming the following data:

	SOUTHERN PINE.	SPRUCE.
E =	2,000,000,	1,200,000;
R =	12,960,	10,080.

That in storehouse floors,

$f = 6$, for fixed loads; $2f = 12$, for live loads.

The limit of d in mill floors, .075 inch per 8 feet, say $\frac{1}{1200}$ span. For 25 feet beams, same curvature = about .75 inch = $\frac{1}{400}$ span.

We find: In a beam loaded at centre and supported at ends,

$$R = \frac{18Wl + 9wl^2}{bh^2}; \qquad E = \frac{432Wl^3}{bh^3d}$$

Strength of beams. Load uniformly distributed:

$$w = \frac{Rbh^2}{9fsl^2}; \qquad l = \sqrt{\frac{Rbh^2}{9wfs}}; \qquad h = \sqrt{\frac{9wfsl^2}{Rb}}$$

Strength of floor plank Load in bulk (as grain):

$$w = \frac{4Rh^2}{3fl^2}; \qquad l = \sqrt{\frac{4Rh^2}{3wf}}; \qquad h = \sqrt{\frac{3wfl^2}{4R}}$$

Strength of floor plank. Load in case or bale:

$$w' = \frac{4Rh^2 - 3ufl^2}{12fl}; \quad l = \sqrt{\frac{4Rh^2}{3f(4w' + u)}};$$

$$h = \sqrt{\frac{3fl^2(4w' + u)}{4R}}$$

Then in a storehouse, with floors of spruce plank; beams of Southern yellow pine, 8 feet between centres, and height of beam = twice breadth.

The strength of beams:

$$w = \frac{15h^3}{l^2}; \qquad l = \sqrt{\frac{15h^3}{w}}; \qquad h = \sqrt[3]{\frac{wl^2}{15}}$$

Strength of floor plank:

$$w' = \frac{35h^2 - u}{4}; \quad l = \sqrt{\frac{2240h^3}{4w + u}}; \quad h = \sqrt{\frac{4w' + u}{35}}$$

Deflection of beams:

$$d = \frac{270wsl^4}{Ebh^3}; \qquad w = \frac{Ebh^3d}{270sl^4}; \qquad h = \sqrt[3]{\frac{270wsl^4}{Ebd}}$$

Deflection of floor plank *one* bay in length—a form of construction not advised:

$$d = \frac{45wl^4}{2Eh^3}; \qquad w = \frac{2Edh^3}{45l^4}; \qquad h = \sqrt[3]{\frac{45wl^4}{2Ed}}$$

Deflection of floor plank *two* bays in length:

$$d = \frac{28wl^4}{3Eh^3}; \qquad w = \frac{3Edh^3}{28l^4}; \qquad h = \sqrt[3]{\frac{28wl^4}{3Ed}}$$

Torsional Strains rarely occur with timber, and but little has been definitely known, until recently, of the value of the different woods to resist this kind of stress.

The following values were determined in British measure by the Author, who used a machine designed for the purpose, which recorded its own action by pencilling a curve whose abscissas represented twisting moments, and whose ordinates represented the corresponding values of the angle of torsion.*

COEFFICIENTS OF TORSION.

	G.	*γ.*
Ash	410,000	0.001,055
Cedar, Red	890,000	0.000,701
Chestnut	355,000	0.001,783
Hickory	910,000	0.000,695
Locust	1,225,000	0.000,517
Mahogany	660,000	0.000,960
Oak	570,000	0.001,111
Pine, Spruce	211,000	0.003,000
" Yellow	495,000	0.001,280
" White	220,000	0.002,880
Walnut, Black	582,000	0.001,090

When *Rupture by Torsion* occurs, the outer layers of fibres will be broken first. Up to the limit of elasticity of these fibres, the strain upon any one fibre will vary approximately as its distance from the axis of torsion.

Where C = coefficient of rupture,
d = the diameter, in inches or centimetres,
P = the twisting force, in pounds or kilogrammes,
l = the lever arm of P.

We shall have for cylindrical pieces,

$$P = \frac{C\pi r^3}{2l}; \qquad r = \sqrt[3]{\frac{2Pl}{C\pi}}$$

* *Journal Franklin Institute* for 1873, p. 254.

The following values for A have been determined by the Author by experiments with recording apparatus, and for the simplified equations

$$d = \sqrt[3]{\frac{Pl}{A}} \quad \text{and} \quad P = \frac{Ad^3}{l}.$$

COEFFICIENTS OF TORSION.

	METRIC.	BRITISH.		METRIC.	BRITISH.
Ash	.328	41.0	Black Spruce	.216	27.0
Cedar, Red	.244	30.5	Heart	.264	33.0
Chestnut	.296	37.0	Sap	.316	39.5
Hickory	.644	80.5	Pine, Spruce	....	....
Locust	.648	81.0	" White	.185	23.1
Oak	.424	53.0	" Yellow	....	....
Mahogany, Spanish	.524	65.5	Walnut, Black	.412	51.5

Cauchy makes C about four-fifths the value of the coefficient of transverse rupture; but this relation must probably be variable.

RELATIVE TORSIONAL RESILIENCE.

NAME.	VALUE.	NAME.	VALUE.
White Pine	1.00	Yellow Pine	3.87
Spruce	1.50	Black Walnut	3.95
Red Cedar	1.61	Locust	5.80
Spanish Mahogany	1.65	Oak	6.60
Ash	2.25	Hickory	6.90
Chestnut	2.40		

Extended and delicate researches upon the laws of resistance to torsion were made by M. G. Wertheim.*

His most important conclusions were the following:

(1.) The torsion angle consists of two parts, one of which is temporary, the other permanent. The latter increases continually, but not regularly.

(2.) The temporary part increases more rapidly than the applied moment, up to the limit of elastic resistance, and, in some cases, beyond.

(3.) The temporary part does not precisely vary with the length twisted. The shorter the piece, the greater this disproportionality.

(4.) Torsion causes a diminution of volume in homogeneous substances, the density increasing from the centre to the circumference. The diminution is proportional to the product of the length of the piece, and the square of the angle of torsion.

These conclusions are deduced from experiments upon small angles of torsion.

Effect of Prolonged Stress upon the Strength and Elasticity of Pine Timber.†—Experiments made by Mr. Herman Haupt showed that timber may be injured by a prolonged stress far within that which leaves the material uninjured when the test is made in the usual way and occupies a few minutes only.‡ An extended series of experiments made intermittently in the Mechanical Laboratory of the Stevens Institute of Technology, Department of Engineering, included an examination of this subject, and the result has confirmed Haupt's earlier work, and has given a tolerably good idea of the effect of prolonged stress in modifying the primitive relation of stress and strain where the wood is good Southern yellow pine.

A selected yellow pine plank was obtained for test, the

* *Annales de Chemie et de Physique*, vol. xxiii., 1st series, vol. l., 3d series.

† From the Proceedings of the American Association for the Advancement of Science, vol. xxx., Cincinnati Meeting, August, 1881. R. H. Thurston.

‡ Bridge Construction, N. Y., 1871, p. 61.

origin and history of which could be traced and the extent of seasoning known beyond all doubt.

The Author, from an examination of the results, concluded that a load of 60 per cent. the maximum given by the usual form of test, is for such pieces unsafe, although it would seem that a slightly smaller load might have been carried indefinitely, or until decay should weaken the timber. A factor of safety of two would possibly have permitted indefinite endurance under static load.

Taking the probable breaking load under unintermitted stress as 50 per cent. that sustained as a maximum under usual tests, and *then* applying a factor of safety of two, we obtain a safe factor, based on the ordinary test, 4.

Conclusions.—In brief, the conclusions to be drawn from the research referred to, are evidently that small sections of yellow pine timber yield steadily over long periods of time under loads exceeding 60 per cent. the maximum obtained by ordinary tests of their transverse strength, and finally break after a period, which with the lighter loads may exceed a year; that deflections half the maximum reached under test may be unsafe for long periods of time, and that a factor of safety of at least 4 should be used for permanent static loads when the character of the material is known.

The author would, in the light of what is now known, always use a factor of safety of at least 5 under absolutely static loads, and when the uncertainties of ordinary practice as to the exact character of material, and especially where shake and the impact of live loads were to be considered, would make the factor not less than 8, and for much of our ordinary work 10.

Conclusions relative to the application of Wood in Engineering Construction.—From what has been already learned, and by comparison with that which is hereafter stated concerning other materials used in engineering, some conclusions may now be deduced, relative to the value of wood to resist the various kinds of stress which the engineer is compelled to meet in his constructions, and for special applications.

For pattern-making a light wood is generally desired, capable of seasoning without checking, and of being easily worked. For large patterns, white pine or cherry is generally used; and for small patterns, where weight is less objectionable, and where strength, smoothness of grain, and firmness of texture are more essential, mahogany is taken. For extremely small patterns, boxwood and ebony are much used.

For turned work, alder, beech, birch, and white pine are used when an easily worked wood is desired; for a tough and fine-grained, clean and smooth-working material, holly is unexcelled; it requires, however, great care in seasoning. Apple, maple, pear, locust, boxwood, ebony, oak, and elm are all valuable for lathe work.

Black walnut, mahogany, and rosewood are used for ornamental purposes, and work well in the lathe as well as at the bench.

For ordinary joiner's work, the pines are principally used, and for finer work, maple, black walnut, and mahogany are in request.

Rosewood and some other tropical woods are generally used only for expensive work, such as is never necessary for the engineer to construct.

Where extreme lightness is desired, white pine is generally used; for purposes requiring a wood both light and strong, yellow pine is most called for.

Woods of Commercial Value in connection with properties usual or peculiar as named at their heads respectively, are as follows:

Elasticity.—Ash, hickory, hazel, lancewood, chestnut (small), yew, snakewood.

Elasticity and Toughness.—Oak, beech, elm, lignum-vitæ, walnut, hornbeam.

Even Grain (for carving and engraving).—Pear, pine, box, lime-tree.

Durability (in dry works).—Cedar, oak, poplar, yellow pine, chestnut.

Wet Construction (as piles, foundations, flumes, etc.).—Elm, alder, beech, oak, plane tree, white cedar.

Ship-building.—Cedar, pines (deals), firs, larches, elms, oaks, locust, teak.

House-building.—Pines, oak, white wood, chestnut, ash, spruce, sycamore.

Furniture.—Common: beech, birch, cedars, cherry, pines, white wood. Best furniture: amboyna, black ebony, mahogany, cherry, maple, walnut, oak, rosewood, satinwood, sandalwood, chestnut, cedar, tulipwood, zebra wood, ebony.

Machinery and Millwork.—Frames: ash, beech, birch, pine, elm, oak. Rollers, etc.: box, lignum-vitæ, mahogany. Teeth of wheels: crab-tree, hornbeam, locust, hickory, and maple. Foundry patterns: alder, pine, mahogany, cherry.

Of the above-named varieties, those that chiefly enter into commerce in this country are oak, hickory, ash, elm, pines, black walnut, maple, cherry, butternut, white wood, etc. No approximate figures even can be given of the amount annually used in this country.

In parts requiring great strength and toughness, white oak, hickory, and locust are used.

The first named is used for water-wheel shafts, for places where lignum-vitæ cannot be used, for subaqueous bearings —as for steps for turbine wheels—and for any position in which it will be kept constantly wet.

Hickory and white oak are particularly well adapted for teeth of mortice-gear wheels, as are also maple and beech; and the former for any dry situations in which their great strength and toughness are likely to be found requisite. Locust is selected where strength and toughness are desired, and where large pieces are not necessary. The last five woods, and maple and the pines, are those most frequently used by the mechanical engineer.

In the drawing office, boxwood, holly, and red cedar are used for the blades of *T*-squares, and for rulers, and scales. Some of the ornamental woods are used for the heads of *T*-squares.

Pearwood is found to be well adapted for model work, and maple for general light work requiring a good surface.

The latter makes good teeth for mortice wheels which are

not subjected to very heavy stress. Sour applewood is even better for the latter purpose, and is much sought by wheelwrights for gearing used in dry situations. In presence of moisture, white oak is the best of all woods for this work. When wood is required in carpentry, for floor-joists and rafters, the stiff woods are selected; for carriage-shafts and poles, builders select the toughest woods, while for tie-beams, those woods having greatest lateral cohesion and tensile strength are taken. In building railroad cars, where lightness and strength should be well combined, pine is preferred above all other woods.

Tough and cross-grained woods are most difficult, and therefore most expensive to work; the most brittle woods are usually easily worked, the fine-grained woods take the smoothest polish, and the surface is best preserved by the harder varieties.

The Figure of the Markings of Wood depends more upon the particular directions of the fibres than upon any difference of color. If a tree were formed of cylindrical layers, the horizontal section would exhibit concentric circles, the vertical section giving parallel straight lines; and the oblique section, ellipses. But few trees are to be found exactly straight, and, therefore, although the three sections have a general tendency to exhibit the figures described, every bend and twist in the tree disturbs the regularity of its fibre, and adds to the variety of grain and ornamentation of the wood. A perpendicular cut through the heart of the tree exhibits the most diversified surface, because in it occurs the most profuse mixture of the fibre, the oldest and newest being presented in the same plank.

Curls are formed by the confused filling in of the space between the forks of the branches. The figures thus produced cause a log to be valuable in proportion to the number of curls it contains.

Figures are also produced in the following manner. The germs of the primary branches are set at an early period of the growth of the parent stem, and thus give rise to knots. But many fail to penetrate to the exterior, and are covered

over by later annual rings. When the germ forces its way to the surface, the fibres of the trunk bend aside when they encounter the knot, and in the soft woods do not unite with it. The hardness of knots is due to the close grouping of the fibres, and to their compression by the surrounding wood, which itself is allowed to expand by the yielding of the bark.

The same operation goes on in the roots of trees, and furniture veneers are often obtained from them. The bird's-eye maple has points or spines on the inside of the bark, which penetrate the wood and make irregular indentations. These cause that peculiar appearance from which the wood takes its name.

In woods, the figure of which resembles the ripple-marks of the sea on fine sand, such as satinwood, sycamore, mahogany, and ash, the figure is produced by the serpentine form of the grain. The fibres of all such pieces are wavy in planes at right angles to that on which the ripple is observed, if not on both, those parts of the wood which receive the light being brightest.

Woods having silver grain, or marked medullary rays, exhibit a dappled appearance similar to that produced on silk by threads crossing one another. English oak, Riga and Dutch wainscot logs, Austrian wainscot, etc., have this peculiarity. In the oak plank the principal lines are the edges of the annual rings, which show parallel lines.

Damask pencillings, or broad, curly veins and stripes, are caused by groups of the medullary rays which undulate from the surface to the centre of the tree, and creep in betwixt the longitudinal fibres. Were the fibres of trees arranged with the uniformity and exactitude of a piece of plain cloth, they would show an even, uninterrupted color; but being arranged in irregular, curved lines, every section partly removes some and exposes others, thus producing a great variety of figure.

Coloring of Woods.—Some woods are nearly uniform in color, and some have several shades of the same hue or of several colors. In the transverse section of such woods the tree seems to have clothed itself with different coats of

various colors. Tulipwood, kingwood, zebrawood, and rosewood illustrate this case. In ordinary planks these markings are drawn out into stripes, bands, and patches, or wavy figures of beautiful or grotesque form.

Woods variegated both in grain and color are generally employed for objects with smooth surfaces, as in cabinet-work. Such are Amboyna, kingwood, mahogany, maple, partridge, rose, satin, snake, tulip, and zebrawood. Specimens of marquetry often beautifully illustrate the use of such wood for the purpose of ornamentation. The same style of work in mouldings has an inferior effect.

The colors of "fancy woods" are not usually liable to fade by exposure to light, tulipwood being one exception; but age darkens them and mellows the general effect. Only the whitest of varnishes should be laid over them, for the natural tint will easily be spoiled. The rich *greenish* brown of walnut is esteemed for piano-forte cases, for which work, however, rosewood has hitherto been more generally used. The rich, deep orange of Spanish mahogany makes beautiful tables and counter-tops, and the size of the timber adapts it to either use. Honduras mahogany, of a brownish tint, is used for all kinds of superior cabinet-work, while oak is principally employed where durability is a necessity. Pitch-pine is pleasing in color and figure. Rosewood has very rich tints, and is much used.

Carpentry is the art of construction in wood, and properly includes several divisions as joinery, cabinet-making, pattern-making, and ship-construction. The engineer will find special treatises on each subject which will give full information relating to trade methods. In this place only the simplest principles involved in all wood-working can be given.

The fashioning of wood is often done by machinery, and hand labor is only employed in fitting and in forming special shapes or in making constructions which are not called for in such quantities as to justify the building of special machinery for their manufacture.

In constructions of wood the parts are usually straight and simply formed pieces, and stresses are almost invariably

taken either as transverse loads or by compression; wood is unfitted for sustaining tensile forces, as it is extremely difficult to obtain such a secure hold upon the material as to permit the tenacity of the piece to be fully brought into play before fracture occurs by detrusion.

In uniting timber it is advisable to be exceedingly careful to reduce the loss of section by cutting for the joints and fastening to a minimum; to take advantage of peculiarities in the "lay" of the grain wherever possible; to make surfaces exposed to pressure of such shape, and to place them in such a position that the lines of pressure shall be normal to them; to give ample area of bearing surface to insure safety against injury by the maximum stress anticipated; to fit abutting parts perfectly and unite them securely, and to insure, wherever possible, equal strength in the pieces and their fastenings, except in places where it is found advisable to make some one point somewhat weaker than the others in order that, in case of accidental rupture, the most costly piece shall be saved at the expense of one that can be better spared. Precaution is necessary to prevent the use of such fastenings, or so locating them that they shall either cut through the wood or crush their bearings. The joints should be simple in form and carefully designed for each case.

Joints receiving compressive stresses are usually made by cutting squarely across the line of pressure; but those made to resist either transverse or tensile forces are less simple.

Scarfing is the most usual method, and practiced in several ways, as is seen in the accompanying sketches: *

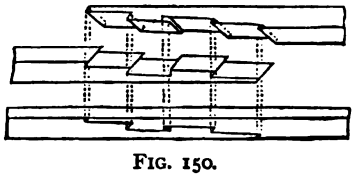


FIG. 150.

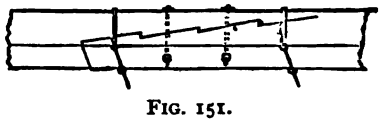


FIG. 151.

In the examples, Figs. 150 and 151, the pieces to be joined

* See Appletons' Cyclopædia of Applied Mechanics.

are cut diagonally at the abutting ends and a stepped surface formed on each side in such a manner that, being fitted and bolted together as shown, the joint becomes nearly as strong as the solid wood; to obtain still greater strength of joint the upper and lower surfaces of the scarf are sometimes covered by a pair of "fish-plates" of boiler-iron extending some distance each way beyond the joint and bolted on by through-bolts having their heads bearing on one plate and their nuts on the other.

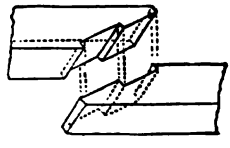


FIG. 152.

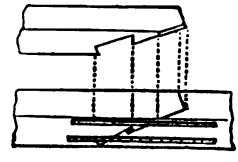


FIG. 153.

In other cases joints are made as in Figs. 152, 153, above, and the lap observed in the second sketch is brought to a bearing by a key of hard wood driven into place after the parts are fitted together, as is also seen in Fig. 150.

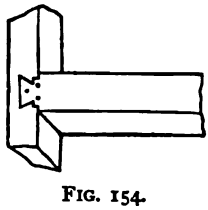


FIG. 154.

Pieces brought together at right angles are often dovetailed as in Fig. 154.

For other cases, tenons, or the end of one piece fitting into mortices, cut through the bearing surface as in the sketches below, are adopted, and when the tenon enters at such an inclination as

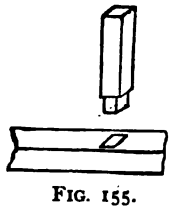


FIG. 155.

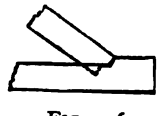


FIG. 156.

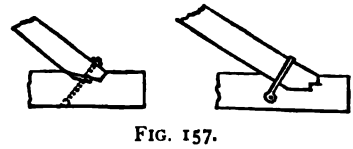


FIG. 157.

to give rise to danger of slipping under the load or splitting out, the use of a bolt or a strap, as shown, will give security.

King-posts are united with diagonal, as with rafters

(Fig. 158), with braces and tie-beams (Fig. 159), as here shown, and straps or bolts are often added for greater safety. The vertical and one diagonal may be united as in Fig. 160.

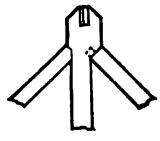


FIG. 158.

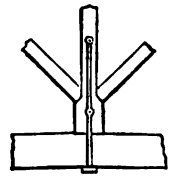


FIG. 159.

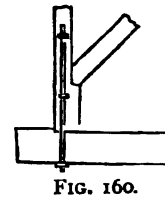


FIG. 160.

The bridge-work timber verticals and diagonals often rest on cast-iron shoes which have a broad bearing on the chords, and thus give security against crushing; this is also practised in the construction of heavy wooden roof-frames.

Timbers crossing each other are often halved together or are lapped when simply abutting. The length of scarf or other joints must be such that the total resistance to detrusion shall be at least equal to the resistance to transverse rupture; the hard woods, as oak, hickory, ash, elm, locust, are usually scarfed to a length equal to six times their depth; pine and other soft woods are given twice as long a scarf.

Wooden girders should have good bearings at the ends, and should rest on the solid wall and have a bearing on stone or iron, with ample space for circulation of air.

Pins used in securing parts of timber-work are often made of wood and are called "treenails"; their diameter is usually about one-third the thickness of the planks which they unite; they are best made of oak or locust, and may be taken as having a strength of 3,000 to 4,000 pounds per square inch (210 to 280 kilogrammes per square centimetre) of cross-section.

Nails are used in small and spikes in large sections of wood-work, and are given a length of from two to three times the thickness of the thinner of the two parts united by them. The following table from Bevan's experiments shows the relative value of several standard sizes:*

* Tredgold: Carpentry.

HOLDING POWER OF NAILS IN PINE.

KIND.	LENGTH.		NO. PER		DEPTH DRIVEN.		RESIST. TO DRAWING.	
	In.	Cm.	Kilogs.	Lbs.	In.	Cm.	Kilogs.	Lbs.
Brads.....	0.44	1.12	4,560	10,000	0.4	1.00	22	48.4
Brads.....	0.53	1.35	3,200	7,040	0 44	1.12	37	81.4
Brads.....	1.25	3.18	618	1,360	0.50	1.27	58	127.6
Fivepenny.	2.00	5.08	139	306	1.50	4.81	320	740.0
Sixpenny..	2.50	6.35	73	160	1.00	4.54	187	411.4
Sixpenny..	2.50	6.35	73	160	1.50	4.81	327	719.4
Sixpenny..	2.50	6.35	73	160	2.00	5.08	530	1,166.0

The weight of nails is often roughly taken as about $W = 0.4l^3$ when W is weight in pounds per 1,000, and l their length in inches; in metric measure $W = 0.06l^3$ for kilogrammes and centimetres. The resistance to a drawing force varies as roughly as $d^{\frac{3}{2}}$, when d is the depth to which the nail is driven. Bevan found the following to be the resistance of a sixpenny nail driven 1 inch (2.54 centimetres) into different woods:

	KGS.	LBS.		KGS.	LBS.
Pine, across grain.....	187	411.4	Pine, with grain.....	87	191.4
Oak.....	507	1,115.4	Elm, " "	257	565.4
Elm.....	327	829.4			

The resistance to driving by steady pressure is, in soft woods, 20 per cent. greater than resistance to extraction. A sixpenny nail forced into Christiania "deal" offered resistance as below:

DEPTH.	Inches.....	0.25	0.5	1.	1.5	2.
	Centimetres.....	0.64	1.77	2.54	3.81	5.08
PRESSURE.	Lbs.....	24	76	235	400	610
	Kilogs.....	11	34.5	107	171	276

Wellington* found the resistance of railroad spikes driven into various woods to be:

WOOD.	DRIVING IN.		PULLING OUT.		WOOD.	DRIVING IN.		PULLING OUT.	
	Lbs.	Kgs.	Lbs.	Kgs.		Lbs.	Kgs.	Lbs.	Kgs.
Beech.....	6,743	3,074	5,978	2,717	Oak, green.....	5,820	452,6	6,523	2,965
Ash.....	5,953	2,750	4,560	2,074	" seasoned...	6,433	2,924	4,281	1,946
Elm.....	4,606	2,094	3,690	1,580	Chestnut.....	3,691	1,580	3,260	1,936
Maple.....	3,843	1,746	3,111	1,323	Hemlock.....	2,106	1,323	1,996	907

It was found that elm and ash will hold a spike about two-thirds as well as oak or beech, and a third better than chestnut; soft maple and sycamore are four-fifths as effective as chestnut, two-fifths as good as oak and beech, and a half better than hemlock.

Wood-screws are used wherever the parts are to be again separated; where the stresses are likely to be greater than can be safely resisted by nails; where the pieces joined are liable to be split or otherwise injured by the use of nails, or where nicety of fitting is important. Their resistance is nearly as the square of their diameters, if made of such length that their full strength may be utilized; shorter screws, or any screws that pull out without breaking, resist merely as the area fractured, *i. e.*, about as the product of the length of screw holding in the wood and diameter outside of thread. Bevan pulled screws 0.22 inch (0.5 centimetre) in diameter over the thread, having twelve threads per inch (5 to the centimetre), from a depth of a half inch (1.27 centimetre), thus:

Beech.....	460 to 990 lbs. 210 " 450 kgs.	Mahogany	770 lbs. 350 kgs.
Ash.....	790 lbs. 360 kgs.	Elm.....	665 lbs. 300 kgs.
Oak.....	760 lbs. 345 kgs.	Sycamore	830 lbs. 377 kgs.

* *Railroad Gazette*, No. 51, p. 668.

HOLDING POWER OF SCREWS.

LENGTH.		NUMBER.			Distance screwed into wood. Cm.	Kilogrammes. Average resistance.	Distance screwed into wood. Inches.	Average resistance. Pounds.				Relative resistance. Taking resistance of 1½ in. screw = 943 as 1.
Of screw in inches.	Of thread on screw. Inches.	Common number of screw.	Threads to 1 inch.	Threads to 1 cm.								
3	1¼	20	8	3.2	6.4	1312	2½	2886	Fine grain dry white ash.			3.06
								2424	Coarse grain dry white ash.			2.57
3	1¾	20	8	3.2	6.4	1102	2½	2879	Black walnut.			3.05
2½	1¾	15	9	3.6	5.1	1217	2	1857	Coarse grain dry white ash.			1.97
2½	1¼	14	10	4.0	5.1	844	2	1813	"	"	"	1.92
2	1¾	20	8	3.2	3.8	824	1½	1586	"	"	"	1.69
2	1¼	16	9	3.6	3.8	721	1½	1633	"	"	"	1.73
2	1¼	14	10	4.0	3.8	733	1½	1580	"	"	"	1.67
2	1¼	12	12	4.8	3.8	709	1½	1549	"	"	"	1.64
1½	¾	16	9	3.6	2.5	519	1	1142	"	"	"	1.21
1½	¾	14	10	4.0	2.5	538	1	1185	"	"	"	1.25
1½	¾	10	13	5.1	2.5	438	1	943	"	"	"	1.00

When bolts and nuts are used, the wood should be protected by giving their heads and nuts a broad bearing on washers, 1½ to 2 times the diameter of the head for hard and soft woods respectively.

Iron fastenings should be avoided where the wood has an acid sap, as do some oaks. The sap of teak and of the pines protect iron fastenings. Where used they should be protected by paint, oil, or coal-tar, or by galvanizing.

Glues.—*Common Glue.*—The absolute strength of a well-glued joint is given as:

HOLDING POWER OF GLUE.

	POUNDS PER SQ. IN.		KILOS. PER SQ. CM.	
	Across the grain, end to end.	With the grain.	Across the grain, end to end.	With the grain.
Beech.....	2,133	1,095	149.31	76.65
Elm.....	1,436	1,124	100.52	78.68
Oak.....	1,735	568	121.45	39.76
White wood....	1,493	341	104.54	23.87
Maple.....	1,422	896	99.51	62.72

It is customary to use from one-sixth to one-tenth of the above values to calculate the resistance which surfaces joined with glue can permanently sustain with safety. A little powdered chalk strengthens glue.

Marine Glue.—India-rubber, 1 part; coal-tar naphtha, 8 to 12 parts; shellac, 15 to 20 parts; melted together. Use hot.

Glue dissolved in skimmed milk will resist the action of moisture; also glue softened with boiled oil or resin, and one-fourth its weight of iron oxide added.

Water-proof Glue.—Boil eight parts of common glue with about thirty parts of water, until a strong solution is obtained; add four and a half parts of boiled linseed-oil, and let the mixture boil two or three minutes, stirring it constantly.

Preservation of Timber.—The causes of decay in timber have already been stated (p. 605), and the process of decay has been described.

As has been seen, timber should be protected against the deleterious effects of moisture and oxidation, and the attacks of insects. Timber lasts longest either in perfectly dry and well-ventilated places, or where it is kept constantly immersed in water. The problem of preserving timber from decay is fully stated when it is said that the object to be attained is the prevention of oxidation.

Timber which has been thoroughly seasoned by the methods already described, and which is perfectly dry, may be preserved by external applications. Under other circumstances, internal application of various solutions must be resorted to.

Paints and Varnishes are used for the protection and preservation of timber by external treatment. They form a coating upon the surface, which resists the wearing action of the weather, and prevents the entrance into the pores of the wood of either moisture or corroding gases.

Should the wood not have been previously well seasoned, however, paint only hastens decay by confining the moisture and hastening the fermentation of the putrescible matter remaining in the wood.

The following are among the best of this class of preserva-

tive compositions; many of them are recommended in the U. S. Army Ordnance Manual.

The proportions are given for 100 parts by weight of prepared colors, when not otherwise designated.

One gallon (3.79 litres)			of linseed oil weighs..	7.5	pounds	3.41	kgms.
"	"	"	spirits of turpentine..	7.25	"	3.3	"
"	"	"	Japan varnish	7.	"	3.18	"
"	"	"	sperm oil.....	7.12	"	3.23	"
"	"	"	neat's-foot oil.....	7.63	"	3.45	"

BOILED OIL.

Raw linseed oil	103.
Copperas	3.15
Litharge	6.3

Suspend the copperas and litharge in a cloth bag in the middle of the kettle of oil. Boil 4½ hours with a slow steady fire.

DRYER OR DRYING.

Copperas and litharge from the boiled oil	60
Spirits of turpentine	56
Boiled oil	2

The mixture from the boiled oil to be ground and thoroughly mixed with the turpentine and oil.

PUTTY. (FOR FILLING CRACKS.)

Spanish whiting, ground	81.6
Boiled oil	20.4

Make into a stiff paste. If not intended for immediate use, raw oil should be used; putty made with boiled oil hardens quickly.

Also, mix finely sifted oak or other sawdust with linseed oil which has been boiled until it has become glutinous.

WHITE PAINT.

	For inside work.	For outside work.
White lead in oil	80.0	80.
Boiled oil	14.5	9.
Raw oil	0.0	9.
Spirits turpentine	8.0	4.

Grind the lead in the oil, then add the spirits of turpentine.

For woodwork use 1 pound to the square yard for three coats (2.75 kilogrammes per square metre).

LEAD COLOR.

White lead in oil	75.0
Lampblack	1.0
Boiled linseed oil	23.0
Litharge	0.5
Japan varnish	0.5
Spirits turpentine	2.5

Grind the lampblack and litharge separately in oil, then stir into the white lead and oil. Turpentine and varnish are added as the paint is required for use, or when packed in kegs for transportation.

BLACK PAINT.

Boiled linseed oil	73.
Lampblack	28.
Litharge	1.
Japan varnish	1.
Spirits turpentine	1.

Grind the lampblack in oil; mix it with the other oil, then grind the litharge in oil and add it, stirring well. The varnish and turpentine are added last. This paint can be used for iron work.

GRAY OR STONE COLOR, FOR BUILDINGS.

	1st Coat.		2d Coat.
White lead in oil	78.0		100.
Boiled oil	9.5		20.
Raw oil	9.5		20.
Spirits turpentine	3.0		0.
Turkey umber	0.5		0.
Lampblack	0.25		0.25
Yellow ochre	0.00		3.

Mix like the lead color.

A square yard of new brickwork requires, for two coats, 1⅛ lbs.; for three coats 1½ lbs. In metric measures, one square metre requires for two coats .61 kilogrammes; for three coats .81 kilogrammes.

CREAM COLOR, FOR BUILDINGS.

	1st Coat.	2d Coat.
White lead, in oil	66.66	70.00
French yellow	3.33	3.33
Japan varnish	1.33	1.33
Raw oil	28.00	24.5
Spirits turpentine	2.25	2.25

A square yard of new brickwork requires for first coat ¾; for second ⅜ pounds; in metric measures, one square metre requires for first coat .4; for second .2 kilogrammes.

BLACK STAIN, FOR WOOD.

Copperas	1 lb.	.67 kgm.
Nutgalls	1 "	.67 "
Sal ammoniac	.25 "	.17 "
Vinegar	1 gall.	3.79 litres.

Stir occasionally, and it becomes ready for use in a few hours.

Clean and smooth the surface, filling the cracks with black putty, allowing it to harden. Apply the stain two or three times, then leave it a day or two to dry; finally rub with boiled oil until polished.

JAPAN VARNISH.

Litharge	4 lbs.	1.8 kgms.
Boiled oil	88 "	40.0 "
Spirits turpentine	2 "	.9 "
Red lead	6 "	2.7 "
Umber	1 "	.45 "
Gum shellac	8 "	3.6 "
Sugar of lead	2 "	.9 "
White vitriol	1 "	.45 "

Boil over a slow charcoal fire five hours, mixing all the ingredients except the turpentine and a small portion of the oil; the latter is added as required to check ebullition. The mixture must be continually stirred with a wooden spatula, and great care is required to prevent it taking fire.

The turpentine is added when the varnish is nearly cool, and should be well stirred in. The varnish must be put in close cans and kept tightly corked.

Japan varnish may be purchased.

Paraffin Paint.—Mix together good asphalt and paraffin in equal parts, melt, and stir well together. Add a small quantity of finely ground caustic lime, constantly stirring. Apply with a large brush. When this first coat has cooled, put on another coating of pure melted paraffin applied quickly and evenly.

Brown mineral (iron oxide) *paints*, as sold ready for mixing with oil, a paint of "red lead" and oil, or of "zinc white," are all used extensively on iron and for outside work.

Wood work exposed to the weather is repainted, in our climate, at intervals of four or five years.

The woodwork supporting the floors of bridges, and timber in damp situations as in wheel-pits, is sometimes coated with *coal-tar* prepared for use by boiling, and by the addition of a small quantity of chalk to give it body. This is also an excellent application for water-pipes, for smoke-stacks of iron, and other out-of-door ironwork. As a preservative against decay it is also excellent on woodwork, but is often seriously objectionable because of its inflammability. Boiling linseed oil, pitch and vegetable tar, applied hot, are not unfrequently used as external applications, and are found to be very effective preservatives. The soot from bituminous coal, mixed with oil or with coal tar, is a very durable and excellent preservative, shedding water well, and protecting efficiently against oxidation. Fish-oil may also be used in some cases for a similar purpose. *Sulphate of iron*, in oil, has also been found to make a useful paint.

The materials which enter into the composition of paint frequently exert a decisive effect upon its preservative qualities. Adulterated and impure paints may not only lack preservative qualities, but may, by their adulterations, actually hasten decay. The most important constituent of paint is *White Lead*, which should be of good quality, and unmixed with any substances which impair its brightness. Its usual adulterations are chalk and the sulphates of lead and baryta; the latter is the least objectionable.

Zinc White is more expensive, and forms a better basis

than white lead; it, however, works dry under the brush and takes longer in drying; it does not have the covering properties of white lead, but forms, however, a more dense coating, which resists the action of the weather and retains its color better than lead paint. It is frequently adulterated with sulphate of baryta.

Red Lead makes a very durable paint and dries well.

Linseed Oil is one of the most important constituents of paint; it improves greatly by age, and ought to be kept at least six months before using. It can be made a "dryer" by boiling, or by the addition of foreign substances. It dries better than any other oil, has a heavy body, and it is owing to this fact that it is capable of resisting the action of the weather. Pure linseed oil is of a pale, transparent, amber color, very limpid, and has little odor, is comparatively sweet to the taste, and when exposed to the light and air grows lighter in color. In adulterated linseed oil the opposite effect takes place.

Nut Oil and *Poppy Oil* are inferior in quality to linseed oil, and are used to adulterate the latter.

Of the colors, yellow ochre is used as a body color more extensively than any other—the best is very durable in color. Amber, Vandyke, and metallic browns are derived from the iron salts, and are also very durable; they adhere to iron better, and are less affected by the air than the red lead.

The real value of any paint depends upon the quality of materials used in composition, and upon the care used in its mixing and preparation.

Charring the surface of well-seasoned timber is found to considerably increase its durability, and this is the method most frequently adopted for the preservation of those portions of fence posts which are buried in the ground.

An external application of *silicate of sodium* has been advised by Abel, for seasoned timber. It is said to form a hard and very durable coating upon the surface, and to act effectively as a preservative against fire, as well as against decay. The solution is laid on with alternate coats of lime wash. Two or three applications of the silicate of sodium

are required to form each coat. Sulphates of iron and of copper, the chloride of mercury, common salt, and other solutions, are occasionally used for external washes.

The common oil paints are, by far, the most usually applied. Their durability is increased by sprinkling liberally with sand, where circumstances permit.

In timber protected by external treatment, special care is required to fill cracks.

The Saturation of Timber, either seasoned or unseasoned, with antiseptic materials has become a matter of such great importance as to have attracted much attention. Many processes have been tried and recommended, but none are generally used in this country, and very few are practiced at all.

A few seem to be effective, but costly; many are of temporary benefit; others, while seeming to be useful at first, are actually injurious, ultimately destroying the timber which they are intended to preserve.

The external applications above described are of no value in defending the timber against the attacks of wood-boring insects. Sheathing the timber in metal, and one or two methods of saturation, are apparently the only reliable expedients.

Of the processes of preservation of wood by saturation, Kyan's consists in the injection of the *bichloride of mercury* (corrosive sublimate); Burnett used the *chloride of zinc;* Boucherie employed the *pyrolignite of iron;* Margery used the *sulphate of copper;* Bethell saturated his timber with *creosote*, or "dead oil," from gas works; Beer used a solution of borax.

The metallic salts owe their antiseptic property to the fact that they produce coagulation of the albumen, which is the fermentable and perishable part of timber.

The use of metallic salts was proposed nearly a hundred years ago, but the first practical applications were made about a half century ago.

"Kyanizing" was suggested by Sir Humphry Davy, some ten years before the process was patented by Sir R. H. Kyan, in England, in 1832.

The solution used consisted of one pound of the bichloride of mercury in four gallons (1 kilogramme to 33½ litres) of water. Timber thoroughly impregnated with the salt has great durability, but the general adoption of this process is precluded by the cost of materials. A hundred parts of timber absorbed one and a half parts of corrosive sublimate. Where it is brought in contact with iron it produces corrosion, and its application is thus rendered still less frequently permissible.

Kyanized timber was used to some extent in Great Britain and the United States when first proposed.

Among other constructions of timber thus prepared may be mentioned the aqueduct of the Alexandria Canal, crossing the Potomac River at Georgetown.

"Burnettizing" was proposed by Sir Wm. Burnett, in 1838, and has been quite largely practiced for special purposes.

The chloride of zinc, in the proportion of one part dissolved in ten parts of water, is forced into the pores of the wood under a pressure of from one hundred to one hundred and twenty-five pounds to the square inch (7 to 8.75 kilogrammes per square centimetre). Burnett's method was, originally, simple immersion in the solution two or three weeks.

An establishment was organized at Lowell, Mass., in 1856, in which burnettizing under pressure was practiced. Subsequently several railroad companies adopted this method and process, and erected burnettizing works.

The cost of preserving timber by this method, including interest on capital and all other expenses, ranged from five to seven dollars per thousand feet, board measure.

The process is not, however, believed to afford as perfect protection as the more expensive method of kyanizing.

The Bethell Process was also patented in England in 1838, and its cheapness and effectiveness have given it a considerable commercial success, both in Europe and the United States. It consists in the saturation of the wood with bituminous substances obtained by the distillation of coal tar.

Like the metallic salts, these substances produce coagulation of the albumen, and thus destroy the tendency to fermentation. Timber thus prepared is rendered very durable, and the process is comparatively inexpensive. Its use has, however, been given up, in some instances after extended trials, on the ground that the increase in durability was not sufficient to compensate for the expense.

Each cubic foot of timber, under a pressure of 150 pounds per square inch (10.5 kilogrammes per square centimetre), absorbs, in twelve hours, from eight to twelve pounds (1.55 to 0.23 kilogrammes to the cubic decimetre) of the creosote or dead oil.

The smaller amount is the allowance advised for railroad cross-ties. Hard woods absorb least. The strength of timber preserved by this method is unimpaired, and it requires no painting, although, with dry timber, a superficial coating of coal tar is sometimes added. This process has special advantages where the timber is exposed to alternations of dryness and moisture, and is therefore liable to wet rot. The dead oil fills the pores completely, coagulates all albumen, and absorbs all oxygen that may exist free in the wood, and, by its poisonous qualities, it acts as a protection against the attacks of insects. It does not, however, afford perfect protection against the ravages of the white ant of tropical countries. Even marine insects usually avoid creosoted timber, and wood so prepared is therefore used to a considerable extent in submarine work.

The antiseptic element of dead oil is supposed to be the carbolic acid, which is estimated by Prof. Letherby at from one and one half to six per cent. of the whole.

The cost of creosoting 1,000 square feet (3.15 square metres), board measure, of oak or spruce fir, has been given at from five to eight dollars.

The Seely, the Robbins, the Leuchs, and the Hayford Processes are American modifications of the Bethell process.

The SEELY PROCESS consists in subjecting the wood to a temperature between 212° and 250° Fahr. (100° and 121° Centi-

grade) in a bath of creosote oil, for a sufficient length of time to expel all moisture. When all water is thus expelled the pores contain only steam. The hot oil is then quickly replaced by a bath of cold dead oil. The steam in the pores of the wood is thus condensed, and a vacuum is formed, into which the oil is forced by atmospheric pressure and by capillary attraction.

From six to twelve pounds of creosote oil to the cubic foot (0.7 to 1.4 kilogrammes per cubic decimetre) of wood is expended in this process. The amount is dependent upon the use to which the wood is to be put. For piles or other timber exposed to the depredations of worms, twelve pounds is used. An impregnation of ten pounds to the cubic foot costs twenty-five cents. For work in wheel-pits and under foundations, at least ten pounds per cubic foot (1.118 kilogrammes per cubic decimetre) should be used. For piles the usual charge is thirty cents per cubic foot.

The ROBBINS PROCESS consists in treating wood with coal tar or oleaginous substances in the form of vapor.

The wood is placed in an air-tight iron chamber, connected with which is a still or retort, heated by a furnace. When heat is applied, the vapor of naphtha is generated at a temperature of 250° to 300° Fahr. (121° to 149° Centigrade), the creosote oil vapor at 360° to 400° (182° to 204° Centigrade), and the heavier tar oils at 500° to 600° Fahr. (260° to 316° Centigrade). The wood is thus exposed from six to twelve hours.

By this process it would seem impossible to charge the wood with more than a fraction of the amount of carbolic acid and of other component parts of coal tar expended in the Seely process. The latter process is decidedly an improvement on the process of Bethell.

The cost of creosoting 1,000 square feet, board measure, of oak or of spruce fir, has been given as from five to eight dollars.

THE LEUCHS PROCESS, as perfected by Hock, is applied to cross-ties in the following manner:

The ties are introduced into an iron cylinder or reservoir

heated on the outside by a steam jacket. The wood, already as dry as possible, is raised to the highest degree of desiccation by the introduction of steam into the jacket, and when no more vapor escapes from it, a solution of paraffin is forced into the cylinder through a tube, by compressed air. This cylinder has a refrigerating coil which discharges into a closed receiver. Then steam is let into the jacket again. The water boiling and the vapor of petroleum not being able to escape, the pressure inside the cylinder rises to 75 or 100 lbs. per square inch (5.25 or 7 kilogrammes per square centimetre), at which pressure the wood is completely impregnated with the liquid.

When this operation has been prolonged sufficiently, heating is stopped, and the operator waits until the pressure has fallen, and the excess of paraffin can be drawn off into the reservoir. The wood is again heated. When all remaining vapor of petroleum has been absorbed, air is blown into the cylinder to drive out gas, which might incommode workmen while removing the wood.

The paraffin remains distributed among the ligneous fibres, enveloping them with a thin coating, at the same time filling the pores and cellular spaces. The wood is thus well protected against moisture. Nails driven into wood so treated, do not rust as in wood impregnated with metallic salts, and the preserved wood retains its value as fuel.

THE HAYFORD PROCESS is one in which the wood is placed in a cylindrical boiler, into which steam is admitted and atmospheric air forced, until there is attained a pressure of 30 to 40 pounds per square inch (2.1 to 2.8 kilogrammes per square centimetre), and a temperature of 250° to 270° Fahr. (121° to 132° Centigrade), which pressure and temperature suffice to evaporate the sap of boards and two-inch (5.08 centimetre) plank in four or five hours—ten or twelve hours being required for heavy timber. After this, the vaporized sap and steam condensations are drawn out by air pumps. A vacuum is then produced which completely withdraws the vaporized sap from the very heart of the wood. The oil is admitted to the wood through perforated pipes arranged

around the interior of the cylinder, under pressure such as, with the partial vacuum within the cylinder, is equivalent to about 75 pounds to the square inch (5.25 kilogrammes per

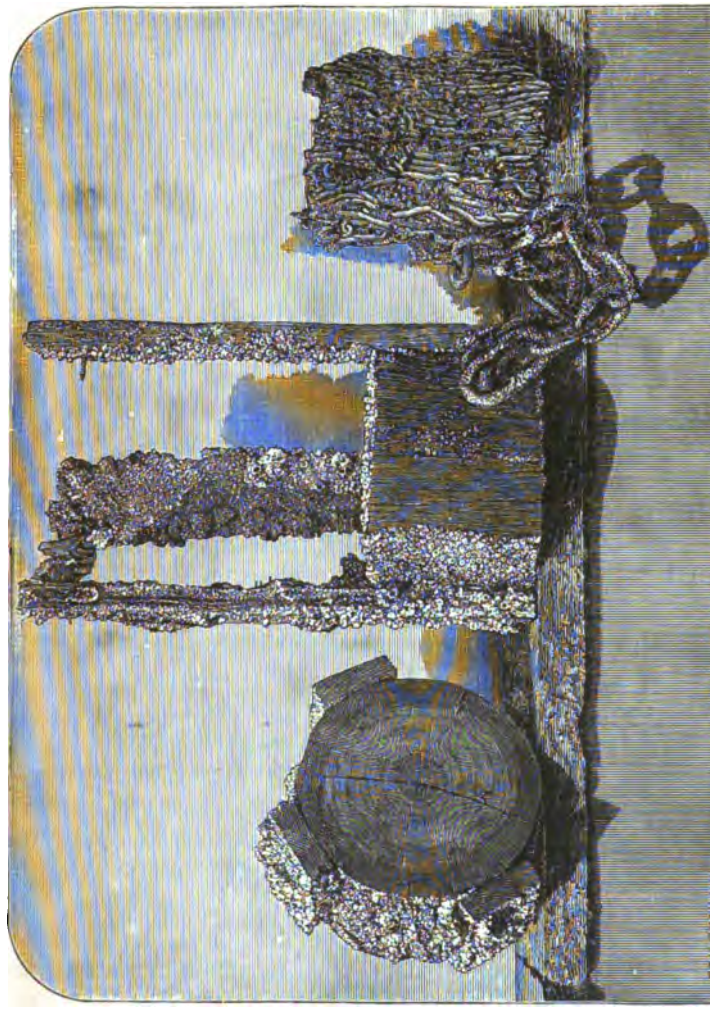


FIG. 161.—WOOD CREOSOTED AND UNCREOSOTED.

square centimetre). This is sufficient to cause the oil to penetrate the more porous woods. For those which are more dense, a further pressure of 60 to 150 pounds (4.2 to 10.5

kilogrammes per square centimetre) is required for a certain length of time.

The illustration on the preceding page exhibits the condition of timber thus creosoted, and uncreosoted, exposed in sea water at Wilmington, N. C. Creosoting is at present considered the most valuable process of protecting wood against the teredo.

M. Paulet considers that the petroleum products containing phenic acid are preferable to metallic salts for treating wood exposed to the action of sea water, because naphthaline, and especially phenic acid, have an antiseptic power, coagulate the albumen, and thus check the circulation of the sap, and also of the blood of parasites ; that the volatility and the solubility of these preservative agents would render their antiseptic action temporary only, if the more fixed and thicker oils which accompany them did not enclose and retain those substances, at the same time obstructing all the pores of the wood, and rendering difficult the access of dissolving liquids and destructive gases ; but that grave objections have been raised, based upon restricted production of these oils, and on the fact that the wood thus impregnated is inflammable, while on the contrary, all the metallic salts render wood uninflammable.

Boucherie's Process, patented in 1839, is an ingenious and inexpensive method of saturation.

This process attracted much attention, and was practiced with considerable success. The timber, freshly cut, and with its terminal foliage still remaining, was set either vertically or horizontally, with the foot immersed in a vat containing the antiseptic solution. The circulation continuing in the trunk of the tree, the sap becomes ejected, and its place is taken by the preservative solution, which is thus thoroughly distributed throughout the fibre.

Growing trees were also treated by the injection of the liquid into their trunks. Where logs, deprived of their foliage and branches, were to be saturated, they were placed on end, and a waterproof bag, or a tank, containing the solution used, was mounted above it, the liquid being thus forced down-

ward through the stick by hydrostatic pressure, driving the sap before it and out of the lower end.

The antiseptic proposed by Dr. Boucherie was crude *pyroligniite of iron.* His process of saturation was largely used with other preservatives also, and his invention of the saturating process seems to have been more generally appreciated than his introduction of a cheap antiseptic. Where it can be conveniently applied, it is exceedingly efficient.

Numerous and elaborate experiments were tried by Dr. Boucherie, in which the action of pyrolignite of iron was carefully noted. He found that one-fiftieth of the weight of the green wood was a sufficiently large proportion of the antiseptic to insure preservation. The hardness of the wood was stated to be doubled by the use of the pyrolignite.

Solutions of deliquescent salts were applied by Dr. Boucherie in the way described, and were found, in the case of chloride of lime and some others, to increase the flexibility of timber. He therefore proposed the use of such solutions, with the addition of one-fifth their quantity of pyrolignite of iron, when it was desired that the wood should retain its moisture, and its flexibility and elasticity. The same inventor proposed, as a cheap substitute for these solutions, the stagnant water of salt marshes. Such preparation, it was claimed also, prevented the warping and splitting of wood, which is a frequent consequence of rapid drying, and yet seasoning was said to be expedited by its use. In this case, the solutions were weak, and the wood could be afterward painted over without difficulty. The process was applied by the inventor to the saturation of timber with earthy chlorides, as a protection against fire. These salts, fusing upon the surface of the wood on the application of heat, rendered it quite incombustible.

Wood was dyed with both mineral and vegetable colors by Dr. Boucherie, and the application of the usual method of producing " fast " colors, by the introduction of dye and mordant successively, was thus made practicable. Wood was treated with odorous solutions to give it fragrance, and with resinous matters to make it water-proof.

The French Government, after receiving favorable reports from the Commission of Engineers appointed to examine into the merits of the process, finally conferred upon the inventor the great gold medal of honor. Subsequently a money award was made him, and he surrendered his patent, which thus became public property. This is still considered one of the best processes yet devised.

"**Beerizing**" consists in the saturation of the timber, by any convenient process, with a solution of borax. This is claimed to dissolve the albumen, and the solution may be allowed to remain, the borax having antiseptic properties, or it may be washed out, and the wood then dried is stated to become more thoroughly seasoned and durable than it can be made by the ordinary process of seasoning.

Folacci's Process of securing incombustibility and impermeability of woods consists in their impregnation with a composition consisting of:

Sulphate of zinc	25 parts.
Potassa	10 parts.
Alum	20 parts.
Oxide of manganese	10 parts.
Sulphuric acid at 60° B.	10 parts.
Water	25 parts.
	100 parts.

These chemicals are mixed and heated without the sulphuric acid to a temperature of 45° Centigrade (113° Fahr.), and the acid is then added gradually until solution is completely effected.

It may be applied by Boucherie's or by any other convenient method.

Margery's Process of saturation with sulphate of copper has been found very effective in some instances.

It was applied by the Boucherie method to telegraph poles and to railroad cross-ties many years ago in France, with perfect success as a preservative against decay. When thus prepared telegraph posts last from fifteen to twenty years. They are subjected to the process in the forest di-

rectly after cutting, and while yet full of sap; the expense of thus treating them is usually from one to one and a half dollars per post. The wood is more rapidly and perfectly protected in proportion as it is porous and rich in sap. After undergoing the preservative process the timber is seasoned and becomes very light and portable. Nearly all the posts of the French, German, and Belgian telegraph service are now treated by this process.

The salt used is poisonous to vegetable and animal parasites which appear at the beginning of all organic decomposition. The quantity of the salts of copper should be increased when the wood is intended to be immersed in water or buried in a moist soil, as water dissolves this salt slowly.

There is in wood impregnated with the salts of copper a portion of the sulphate closely united with the ligneous tissue, and another portion in excess remaining free; this latter portion dissolves first, and, carried off by the exterior fluids, only retards the loss of the metallic salt combined with the wood; but this combination itself, although more stable, does not escape removal, which is accelerated or retarded according to the rapidity and ease with which the dissolving liquid is renewed. The quantity of metallic salt should be small in wood intended for constructions in the open air, in order to prevent mechanical injury due to crystallization. Major Sankey found this process equally efficient in India, more recently, as a protection against the attacks of the white ant and other insects. He used a solution of one pound of the salt in four gallons (1 kilogramme to 33⅓ litres) of water. The timber was steeped in the solution two or two and a half days for each inch (2.54 centimetres) in thickness.

A simple coating of *boiled linseed oil* thickened with powdered charcoal, has in some cases been found a very economical and efficient preservative of timber.

Statistics of railroad construction have given the following data:

Of unprotected oak cross-ties on European roads, 25 per cent. were renewed in 12 years, and 50 per cent. in 17 years. When impregnated with chloride of zinc, 3¼ per cent. were

renewed in 7 years, and 20 per cent. in 17 years; when protected by "dead-oil," 0.1 per cent. were replaced in 6 years.

Of pine cross-ties impregnated with chloride of zinc, 4½ per cent. were renewed in 7 years, and 31 per cent. in 21 years.

Of ties of beech, protected by creosote, 45 per cent. were replaced in 22 years.

On the railroad from Hanover and Cologne to Minden, of pine ties injected with zinc, 21 per cent. were renewed after 21 years; of beech ties injected with creosote, 46 per cent. after 21 years; oak not injected, 49 per cent. after 17 years; oak ties injected with chloride of zinc, 20.7 per cent. after 17 years. The ties not renewed appeared perfectly sound.

In all these cases the ties were laid in favorable situations.

It was reported to the German Railway Union, in 1881, that, on the railways of Europe, chloride of zinc was most generally used for preserving timber, and creosoting next, while the use of sulphate of copper was declining. Preservation with chloride of zinc cost less than one half as much as creosoting. Seasoning was considered desirable before creosoting, but not when using the salts of zinc.

The importance of the preservation of timber is daily increasing, not only as a matter of ordinary economical policy, but because the rapid destruction of forests is continually rendering timber more scarce and more costly. It will become a matter of such vital necessity to preserve our forest trees, that legislation will soon inevitably aid in increasing the market value of timber by forbidding its wholesale destruction.

The substitution of iron for wood, in construction, is proceeding so rapidly, that it will afford some relief; but the preservation of timber will nevertheless remain a matter of exceptional importance.

CHAPTER XXI.

MISCELLANEOUS MATERIALS:

Leather; Belting; Paper; India Rubber; Gutta Percha; Cordage.

Leather; Belts.—One of the principal uses of leather in engineering is in its application in the form of belting, for driving machinery. The best quality is well tanned ox-hide, cut from the back of the animal, and very exactly trimmed, to form perfectly straight strips of uniform thickness. These strips, which are from 4 to 6 feet (1.2 to 1.8 m.) long, and usually about three-sixteenths of an inch (0.48 cm.) in thickness, are scarfed, spliced, and cemented end to end, to make any desired length of belt.

"Single" belts are those made of a single thickness of leather. Extra strong belts are made by cementing or riveting together two thicknesses of leather to form a "double belt." Under light loads the single belt has the greatest adhesion; but under heavy loads the double belt is fully as efficient. Double belts are sometimes made 6 feet (1.2 metres) wide, and 100 to 150 feet (30 to 45 metres) long.

The inside of the hide is called the "flesh side;" the outside the "grain side." The belt wears best when placed with the flesh side next the pulley. Some engineers, however, advise the reverse position, as the belt is less liable to slip.

The weight of hard, well-tanned belt leather is about that of water, 62½ pounds per cubic foot (1,000 kilogrammes per cubic metre), and may be taken, at an average, as about 0.85 pounds per square foot (4 kilogrammes per square metre).

The tenacity of belt leather of good quality is about 650 pounds per inch in width (115 kilogrammes per cm. wide), one half that amount when spliced and riveted, and one

third when laced. The safe working tension is given by some engineers as 50 pounds per inch of breadth (9 kilogrammes per centimetre).

Belt lacings are strips of sheepskin, about a half inch (1.27 cm.) wide, and a yard (0.9 metre) or more in length. In joining belt ends, the belt is pulled taut, and, if heavy, stretched and held by "belt-clamps," cut so that the ends just meet, and a single, or double, or even a triple row of holes, according to its size and tightness, punched to receive the lacing. The holes should be exactly in line. The lacing is then passed through these holes, backward and forward, joining the two ends evenly and strongly. Small, strong tempered steel hooks are often used instead of lacing.

Calfskin, well tanned, stretched wet, makes good lacings.

The firmest and best method of uniting leather belts is to scarf the ends so as to lap a distance of not less than ten, nor usually more than twenty, times, their thickness, adjusting the length of the belt carefully by setting up well with "belt-clamps," and then cementing the parts well, finally securing the lap by copper rivets. The next best method is probably that of connecting the ends by steel hooks, and the least effective, but probably most usual, way is by lacing.

The stress allowed on a single belt may be taken at 300 pounds per inch of width (55 kilogrammes per cm.) Morin allows 284 pounds per square inch (20 kilogrammes per square cm.), and Claudel 355 pounds (25 kilogrammes). Rankine takes 285 pounds per square inch of section (20 kilogrammes per square cm.), and assumes the usual thickness as 0.16 inch (0.4 cm.).

In very fast-running belts, the tension given in setting up is sometimes increased by centrifugal action to such an extent that it should be allowed for in calculating the width required. This "centrifugal" tension" is thus measured:

A belt of the section s, density d, and running at the velocity v, in passing from one side to the other of the pulley exhibits energy, in one direction, measured each second by

$$E = sdv \times \frac{v^2}{2g};$$

this energy is first destroyed and then is reproduced in the opposite direction on the other side of the pulley. The total energy is thus:

$$2E = sd\,\frac{v^2}{g}$$

The effort demanded to produce this reversal is $\frac{2E}{v}$,

or,

$$F = \frac{2E}{v} = \frac{sdv^2}{g}$$

The required section of belt now, instead of $s = \frac{T}{t}$, in which T is the total tension, and t is the safe working tension per square unit of section of the material as above, becomes,

$$s = \frac{T}{t - \frac{dv^2}{g}};$$

The Friction of leather belts is relied upon to prevent slipping. This friction is at each point of contact proportional to the pressure there existing, and the total resistance to slipping is obtained by summing the resistances throughout the arc of contact.

The pressure at each point is equal to the tension at that point, as is seen when it is considered that it is the same as would exist were that tension uniform, and were there no friction throughout the arc of contact. But this tension is actually variable in consequence of the existence of friction, and we have, as shown by Rankine,

$$dR = fTd\theta, = dT,$$

when $R = T_1 - T_2$, the working stress, *i. e.*, the difference of tension at the extremities of the arc, $f =$ the coefficient of friction, and $\theta =$ the arc of contact; and

$$\int_{T_2}^{T_1} \frac{dT}{T} = f\int d\theta = \log_e \frac{T_1}{T_2} = f\theta$$

$$R = T_1 - T_2 = T_1(1 - e^{-f\theta}) = T_2(e^{f\theta} - 1),$$

since

$$T_1 = T_2 e^{f\theta}; \quad T_2 = T_1 e^{-f\theta}; \quad T_1 + T_2 = T_2(e^{f\theta} + 1).$$

The mean tension is $\frac{T_1 + T_2}{2}$, and

$$\frac{T_1 + T_2}{2} \div R = \frac{e^{f\theta} + 1}{2(e^{f\theta} - 1)}$$

Since $\theta = 2\pi n$, when n = arc of contact in "turns," $e^{f\theta} = 10^{2.7288 f n}$, and $f = 0.42$. When this arc is expressed in degrees,

$$R = T_1(1 - 10^{-0.0032\theta}).$$

The following are values* of the factors:

When $\theta = \pi$ and $n = \frac{1}{2}$, as where the pulleys are of equal size:

TENSION AND FRICTION OF BELTS.

$f =$	0.15	0.25	0.42
$2.7288 f =$	0.41	0.68	1.15
$\frac{T_1}{T_2} =$	1.60	2.20	3.76
$\frac{T_1}{R} =$	2.66	1.84	1.36
$\frac{T_1 + T_2}{2R} =$	2.16	1.34	0.86

In common practice, it is now usual to take $f = 0.22$, or $f = 0.25$; $T_2 = \frac{1}{2} T_1$, $= R$; $= \frac{T_1 + T_2}{2R} = 1.5$; $R = \frac{1}{3}(T_1 + T_2) = 150$ lbs. per inch (28 kilogrammes per centimetre) of width of belt; but one-half this stress is often observed. An old millwright's rule allows one horse-power for each inch in width running 1,100 feet per minute, *i. e.*,

* Rankine, Machinery and Millwork, § 310.

$HP = \frac{bv}{1100}$; (2.54 centimetres width running 335 metres per minute. Belts are often driven without slip, to nearly double this power.

Nagle gives the following:

For laced belts—$HP = ctvw\,(0.55 - 0.00002157tv^2)$
For riveted belts—$HP = ctvw\,(1 - 0.00002157tv^2)$
when

$c = 1 - 10^{-0.000958f\theta}$;
θ = arc of contact, degrees;
w = width of belt, inches.
t = thickness;
v = velocity, feet per second.

Morin gives the following as maximum coefficients of friction of belts:

FRICTION OF BELTS.

	f.
Common cases, iron pulleys	0.28
Wet belts, " "	0.38
Common belts, wooden pulleys	0.47
New " " "	0.50

Where the arc of contact varies, the value of $\frac{T_1}{T_2}$ may be altered thus ($f = 0.28$):

n =	0.2	0.3	0.4	0.5	0.6	0.8	1.0
$\frac{T_1}{T_2}$ =	1.4	1.7	2.0	2.4	2.9	4.0	5.8

Raw Hide, or untanned leather, when perfectly sound, is much stronger than tanned leather, and is much used for some parts of textile machinery connections, in looms, for ship's tiller-ropes, etc. It is cut from the raw skin and dried in the sun. Its strength may be taken as one-half greater than that of leather; its resistance to violent impact is very great.

The *Cement* used for belts may be made by melting together:* 1 part shellac; 2 parts pitch; 2 parts linseed oil; 4 parts India-rubber; 16 parts gutta percha, until thoroughly incorporated. It is applied warm, in a thin coating, very quickly, and the two parts of the belt are promptly and firmly clamped together and left until completely set.

Leather is used for the packing of pumps, and often for their valves.

Paper is principally used by the engineer in the drawing-room; but it is occasionally applied in the making of belts, of packing and of other needed articles.

Drawing paper for nice work is made of linen rags reduced to a pulp, and formed into thin sheets having a smooth, peculiarly varied surface, which takes ink and colors well, bears erasures, and is strong and durable. The finished drawings are sometimes coated with a solution of shellac in alcohol (1 part shellac to from 4 to 8 of alcohol), which discolors the sheet, but which enables the draughtsman to wash it when soiled, and prevents that rapid soiling which always occurs when working drawings are handled.

Rough drawings are made on cotton paper of a cheap grade, which comes in long rolls of considerable width.

Shop drawings are usually copies on tracing cloth, or photographically prepared "blue prints," made by using the tracing as a negative, and are mounted on a board to avoid injury by rolling or bending.

The principal sizes of drawing paper are:

Medium	18 x22 inches.	Columbia	23x33½ inches.
Royal	19 x24 "	Atlas	26x33 "
Imperial	21½x29 "	Theorem	28x34 "
Elephant	22½x27½ "	Double Elephant	26x40 "

Of tracing paper we have:

Double Crown	20x30 inches.	Grand Royal	18x24 inches.
Double D Crown	30x40 "	Grand Aigle	27x40 "
Double D D Crown	40x60 "		

* Molesworth.

Tracing cloth comes in rolls of various widths, as does vellum writing paper.

Blotting paper is a thick cotton paper, perfectly free from size or greasy matters.

Lithographic paper is made by coating printing paper with a composition of one part alum, two of gum arabic, and six of starch, dissolved in warm water, and laid on hot with a brush. Tracing paper is made by washing printing paper with a mixture of either Canada balsam and oil of turpentine, or nut oil and turpentine, and thoroughly drying before using it.

Copying ("manifold") paper is writing paper coated with lard and blacklead.

Paper of considerable thickness is known as *pasteboard*, and is extensively used for making boxes to contain light materials.

Paper Belts are sometimes used. They consist of a very hard pressed paper, have great strength and considerable durability, but a low coefficient of friction, and are very stiff and unmanageable. The same material makes the exceedingly light and strong boats used for racing purposes. They are formed and compressed in moulds, and are therefore properly "*papier maché*."

Calender Rolls are made of paper formed and compacted by the hydraulic press. This compacted paper becomes as close in texture as hard wood, very strong, with a very fine, smooth surface, and works like a soft metal.

India Rubber and Gutta Percha are used in special forms by the engineer; in bands for belting, in sheets for packing, and, to a limited extent, for various minor purposes.

India-rubber, or caoutchouc, is the dried juice or sap of several tropical trees or shrubs. The best, the "Para gum," is obtained from the *Hevea Braziliensis*, one of the Euphorbiaceæ, Ceara rubber from the *Manihot glaziovii*, and Pernambuco gum from the *Hancornia speciosa*. This gum is also obtained from the East Indies, Africa, and Central America.

Pure rubber, if of good quality, is dry, tough, strong, and

enormously elastic. It dissolves freely in benzole, chloroform, carbon disulphide, and the essential oils; contact with oil or grease rapidly destroys it.

All the rubber used by the engineer is "vulcanized" by heating it and incorporating with it 20 to 30 per cent. of sulphur; it then becomes less readily softened by heat or hardened by cold, and makes very durable water-proof articles of many kinds, all of which are made of woven fabrics smeared with the vulcanized rubber. When the proportion of sulphur reaches 30 or 40 per cent., various grades of "ebonite" are produced—a hard, jet black, moderately elastic substance, used by the engineer for making rulers, scales, "triangles," and curves, and in the arts generally, for a great variety of purposes.

India-rubber Belts are made by weaving cotton canvas of the required length and width, and coating it with vulcanized rubber. These belts are made two, three, or four-ply, as they are required to do work demanding the strength of two, three, or four thicknesses. These belts are considerably stronger than leather belts, are usually truer and run more smoothly, and are perfectly impervious to water; they have a higher coefficient of friction, but, if overloaded, are apt to be rapidly and seriously injured by slipping.

India-rubber Valves are largely employed in hydraulic machines. They should be made of well vulcanized rubber, uniform in thickness, cut precisely or moulded exactly to size and shape, and should have just sufficient thickness to safely sustain the pressure thrown on them. In many cases they outlast metal valves.

Gutta Percha is the dried and hardened sap from the bark of trees of the order *Sapotaceæ*, found plentifully in the Malay Peninsula. When pure it is grayish white, becoming brown and yellow with exposure or from the presence of impurities. It is as hard as the softer woods, and can be easily moulded or rolled into sheets having considerable toughness and without elasticity, resembling in density and texture hard leather, having a specific gravity of 0.98 to 1.00. In solubility it resembles rubber, as well as in nearly all other

properties except elasticity. It is an excellent insulator, and is extensively used in telegraphic engineering. It is also used for belting, the same proportions being adopted as with leather.

Cordage is usually made of hemp, flax, and cotton, and sometimes of leather, rawhide, and often of wire.

Small cordage is known as *rope;* it is usually composed of three or four strands of "yarns," laid up with a right-hand twist, the strands being laid up with a left-hand twist. *Hawsers* are made up with three right-handed strands, and *cables* with three hawsers laid up left-handed. *Shrouds* are made up with a central core, surrounded by four strands.

Tarred Ropes are less subject to injury by the weather than white cordage, but have one fourth less strength. Cordage takes up from 20 to 30 per cent. of its weight in tar. The larger the cordage the less its strength per unit of section; this loss amounts to nearly 50 per cent. in large cables. Three-strand cordage is ten or fifteen per cent. stronger than four-strand, if rope laid; ten per cent. weaker in hawsers and cables.

The working or maximum proof strength of cordage may be calculated by multiplying the square of the girth in inches by 200 to 300 pounds, or in centimetres by 14 or 22 kilogrammes.

White 2-inch (5 centimetres) hemp rope should carry about 5,000 pounds (2,275 kilogrammes), or nearly one ton weight per pound weight per fathom (say 1,200 kilogrammes per kilogramme weight per metre). The U. S. navy test allows 4,200 pounds on a 1¾-inch white hemp rope, or 1,700 pounds per square inch (1,195 kilogrammes per square centimetre). Manilla rope has about two-thirds the strength of good Russian (Riga) hemp.

The method of connection of ropes is usually by making knots; although permanent union is effected by a "splice," in which the two ends are overlaid for a considerable distance, and their strands mutually interwoven, making a connection as strong as the body of the rope.

Knots cannot well be verbally described; but the following

engravings, selected from Molesworth, represent the principal knots used by the engineer and the seaman. In these illustrations, *W* indicates the direction of the weight, *P* that of the pull.

Fig. 162 is the "half hitch," used to secure the end of a line to any object during a steady pull; Fig. 163 is a "timber hitch," employed for the same purpose, when greater security or a more permanent hold is desired. Fig. 164 exhibits the two hitches used together, the timber hitch backing the half hitch; this arrangement is used at sea in towing spars. With the "clove hitch," Fig. 165, the stick is held in position by a pull on each side; the "rolling hitch," Fig. 166, is a still tighter knot than the timber hitch, as it rolls the lines over, and binds itself as soon as the pull is given.

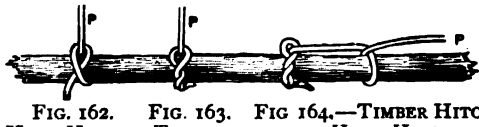


FIG. 162. HALF HITCH. FIG. 163. TIMBER HITCH. FIG 164.—TIMBER HITCH AND HALF HITCH.

FIG. 165.—CLOVE HITCH. FIG. 166.—ROLLING HITCH. FIG. 167.—REEF KNOT.

The "square knot," or "reef knot," Fig. 167, is the simplest and best knot for uniting rope ends; the "sheet bend,"

FIG. 168.—SHEET BEND. FIG. 169.—SHEET BEND WITH TOGGLE. FIG. 170.—BOWLINE.

Fig. 168, is somewhat similar; the "sheet bend and toggle," Fig. 169, is easily unloosed, and the "bowline," Fig. 170, forms a loop which can be thrown, lasso-like, over a post, to which it is proposed to make fast.

Fig. 171 shows the method of putting a "stopper" on a rope or cable, for the purpose of holding it in place while shifting the end, or while fleeting it at a winch. The "black-

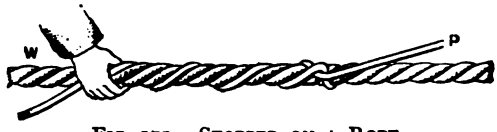


FIG. 171.—STOPPER ON A ROPE.

wall hitch," the "fisherman's bend," the "round turn and half hitch," Figs. 172, 173 and 174, show how a rope may be made

FIG. 172.—BLACKWALL HITCH.

FIG. 173.—FISHERMAN'S BEND.

FIG. 174.—ROUND TURN AND HALF HITCH.

fast to a hook, or to a link or deadeye; the lashing shown at A on the last two makes the line secure.

A "*sling*," or "strop," Fig. 175, which may be either a rope or a chain, has many uses; it is seen in Fig. 176, as used in raising a stone or other heavy mass; in Fig. 177, as used to give a hold for the hook of the tackle; and, in Fig. 178, is illustrated the attachment of stop and "guy ropes" to the head of a derrick.

FIG. 175.—A STROP OR SLING.

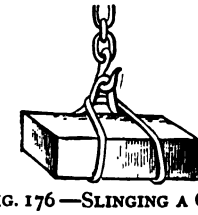
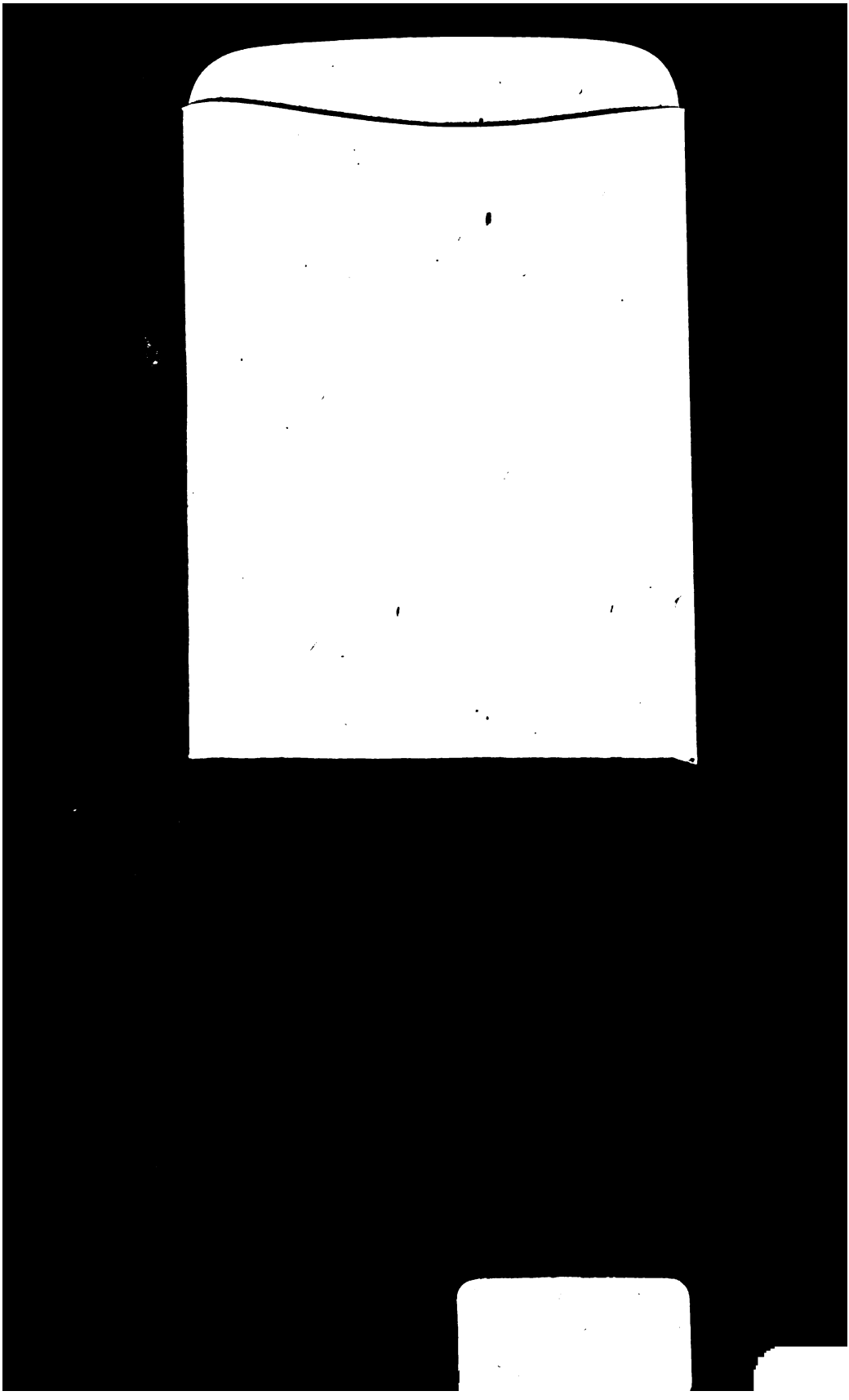


FIG. 176.—SLINGING A CASE.

FIG. 178.—HEAD OF A DERRICK.

STROP ON A ROPE TO HOCK A BLOCK TO.

FIG. 177.

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